NUCLEONICS

September 1953

AEC views on nuclear power are given to Joint Committee on Atomic Energy by Chairman Strauss (left, foreground). Committee (from left) includes Sens. Johnson (D, Col.), Bricker (R, O.), Hickenlooper (R, Ia.), and Reps. Cole, chairman (R, N. Y.), Durham (D, N. C.) Holifield (D, Calif.), and Price (D, Ill.). For an analysis of these hearings on atomic energy legislation, see page 9

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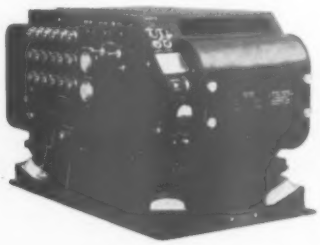

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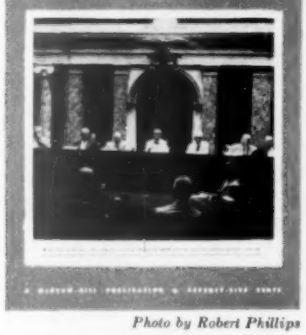

Photo by Robert Phillips

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TWO CHANNEL

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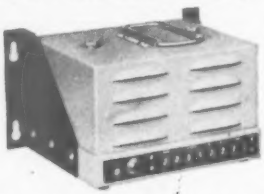

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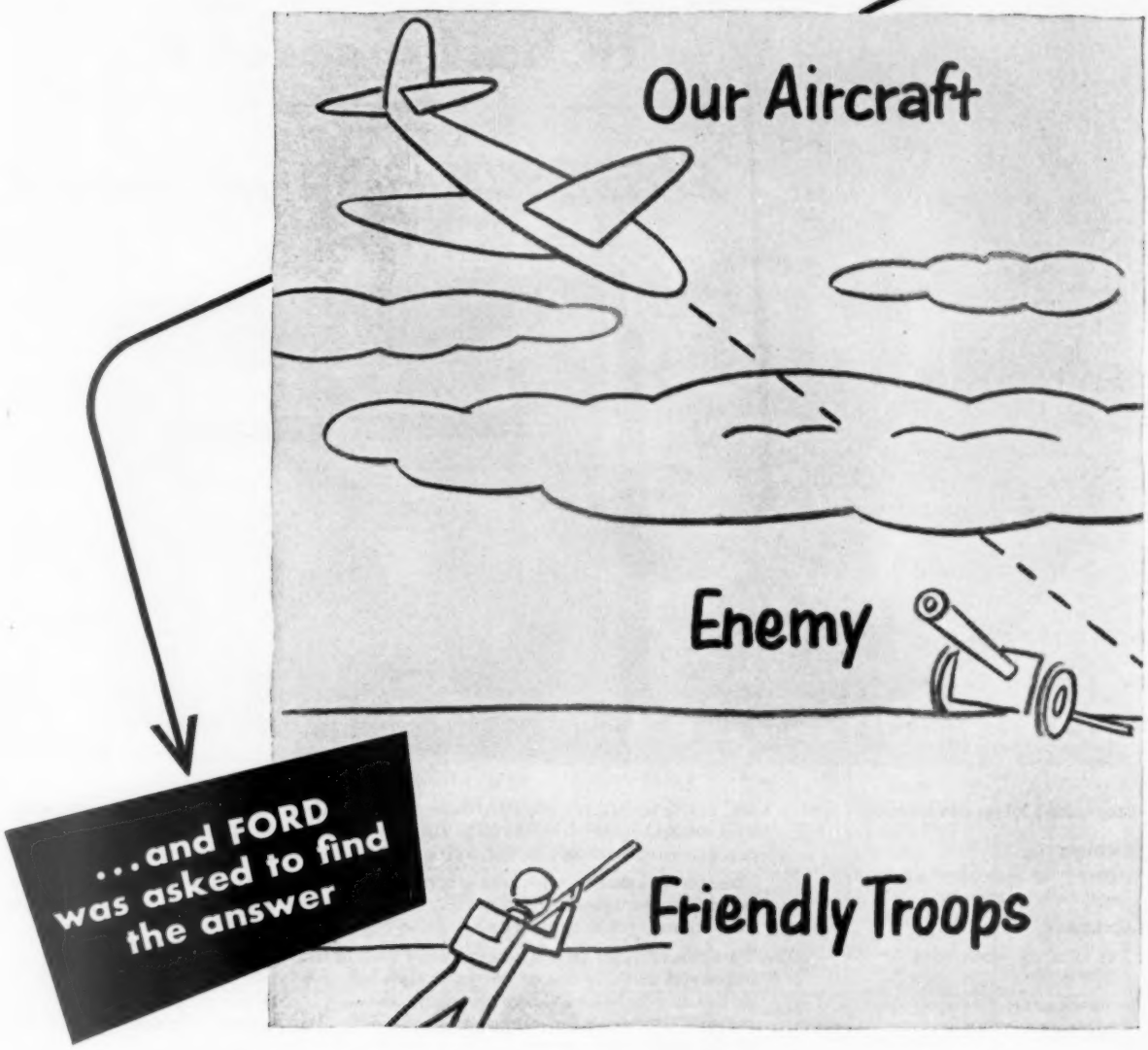

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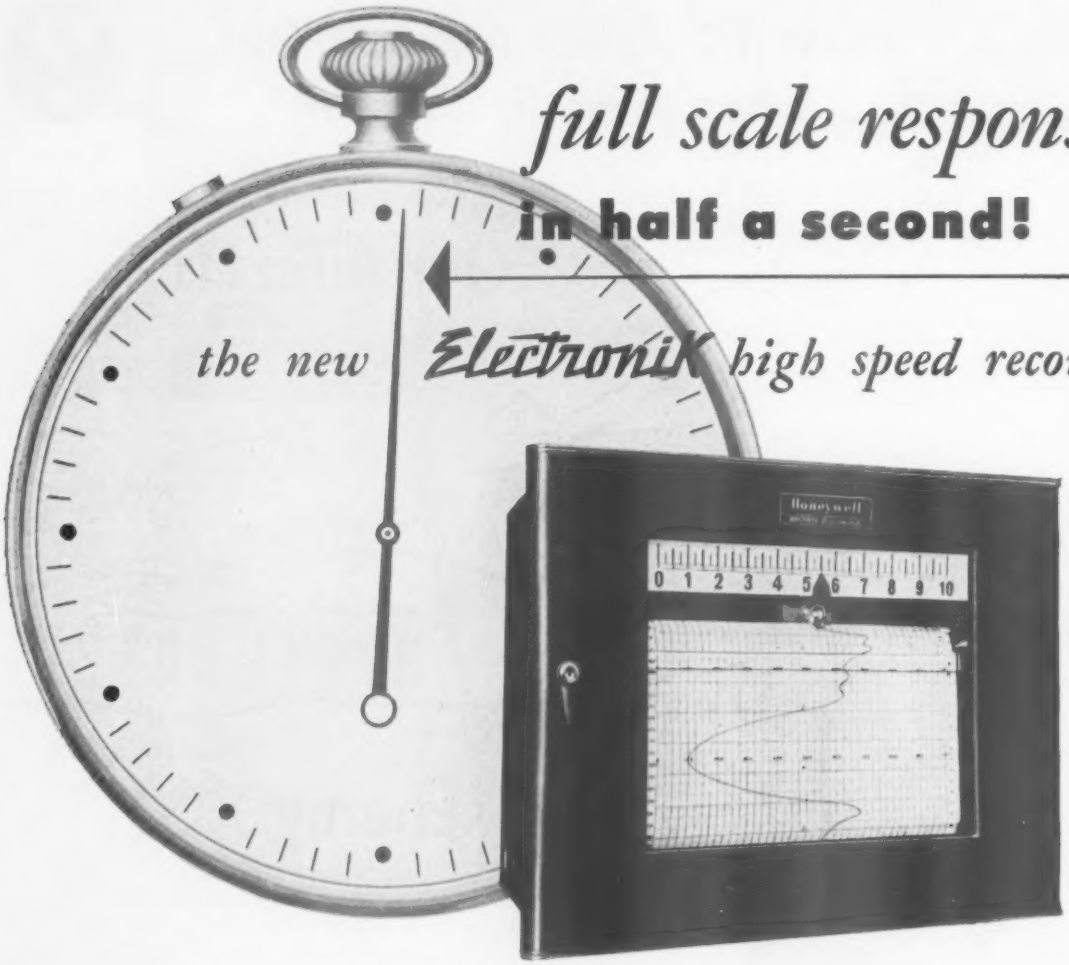

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	HEIGHT	DIAM.					
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OB2	2.63	.75	127	108	5.	30.	3.5
CK1017	2.69	.75	750	700	0.005	0.055	15
CK1022	2.69	.75	1100	1000	0.005	0.055	20
CK1037	1.75	.40	730	700	0.005	0.100	15
CK1038	1.75	.40	930	900	0.005	0.055	15
CK1039	1.75	.40	1230	1200	0.005	0.100	25
CK5651*	2.13	.75	115	87	1.5	3.5	3
CK5651WA*	2.13	.75	115	84.5	1.5	3.5	2
CK5783*	1.63	.40	125	87	1.5	3.5	3
CK5783WA*	1.63	.40	125	86	1.5	3.5	3
CK5787	2.06	.40	135	100	5.	30.	6
CK5787WA	2.06	.40	135	100	5.	25.	4
CK5962	2.69	.75	730	700	0.002	0.055	15
CK6213	1.38	.40	200	130	1.0	2.5	2

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GENERAL ELECTRIC

Should the Atomic Energy Act Be Revised?

.. It's in the Lap of Congress

THE PUBLIC HEARINGS on atomic energy legislation just concluded by the Joint Congressional Committee on Atomic Energy served a very useful purpose. In what previously had been a very confused atmosphere clouded by secrecy, the hearings got into the public record the facts of where all interested parties stand. A springboard now exists from which specific legislative ideas can be formulated.

This is not to imply that there is by any means a clearcut course of action that has been pointed up. In fact, there are some rather basic disagreements.

All are in essential agreement that there is an urgency for this country to develop a strong civilian nuclear power development program. The urgency for this comes not so much from the need for a new, low-cost source of energy as from the vital necessity for this country to maintain international preeminence in reactor technology.

With an assumed need for an aggressive power program, how do we get it? What route do we follow? Government alone? Industry alone? Or a cooperative government-industry venture?

Thus far, the Government has had the sole responsibility in this field. For a multitude of reasons, no substantial program has yet evolved for a direct attack on civilian power.

Now industry comes along and says it wants to be put in a position so that it can spend its own money in the power field. But no one company has told Congress that if the Atomic Energy Act is changed it would invest substantial sums of its own money. Certain members of Congress say why revise the Act if industry isn't ready to lay money on the line.

If in fact industry were ready with its money right now, there would be no question of a legislative change going through. But Congress is unhappy about the subsidization of industry.

The serious interest and intent of industry is clear, however. Already several millions of dollars and high-priced talent have been committed to preliminary activities. But industry is not yet in a position to determine what it will spend.

WITHOUT DOUBT the most controversial problem to be resolved is patents. The other issues—ownership of plants and fuels, security, secrecy, health and safety, etc.—appear relatively easy of resolution, at least in temporary form.

But patent rights are basic to the position of industry in the atomic energy field as they are in all other fields. On the other hand Congress raises the issue of protection of the public interest and investment in atomic energy, and is opposed to the issuance of patents to early entrants into this field that might be unusually restrictive on companies coming in later.

It seems to us that an excellent solution to this problem has been proposed by witnesses Karl Cohen and Casper Ooms (see p. 18). They suggest that any nonmilitary patent considered unusually restrictive be made subject to compulsory licensing to qualified individuals.

Since most industrial witnesses doubted that they would come up with any such unique patentable inventions and since the Cohen-Ooms proposal would protect the public interest in the event of such an invention, the idea should be eminently acceptable to both points of view.

It then follows that there is no reason for the Atomic Energy Act not to be revised. We have nothing to fear and everything to gain.

Industry is expected to be ready very shortly to spend its own money. The way should be clear for this to be possible.

Should the Atomic Energy Act Be Revised?

Six weeks of public hearings by Congress show:

- ★ **Need for aggressive nuclear power program**
- ★ **Favoring of joint government, industry development in next 5 years**
- ★ **Importance of change in legislation to foster industrial activity**
- ★ **Significance of patent problem to Congress and industry**

BOXSCORE OF WITNESS VIEWPOINTS

Government
AEC: *Gordon Dean*
• *L. Strauss*
STATE: *W. B. Smith*
DEFENSE: *R. LeBaron*
INTERIOR: *D. McKay*
COMMERCE: *W. Williams*
Industry
DOW-DETROIT: *W. L. Cisler, T. Gillespie*
MONSANTO-UNION ELECTRIC: *E. J. Putzell, J. W. McAfee*
FOSTER WHEELER-PIONEER: *E. W. Mills, F. C. Kellogg*
COMMONWEALTH EDISON: *W. Gale*
N. AMERICAN AVIA.: *J. L. Atwood, C. Starr*
WALTER KIDDE: *K. Cohen*
NDA: *J. Menke*
WESTINGHOUSE: *G. Price, C. H. Weaver*
G. E.: *F. H. McCune*
AM. MACH. & FOUNDRY: *A. K. Brown*
ALLIS-CHALMERS: *R. S. Stevenson, C. R. Braun*
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BENDIX: *M. P. Ferguson, L. A. Hyland*
SYLVANIA: *W. Kingston*
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CIO: *B. C. Sigal, E. D. Swisher*
AFL: *A. J. Biemiller*
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NEW ENGLAND COUNCIL: *W. Raleigh*
AMER. PUBLIC POWER ASSOC.: *S. B. Morris, A. Radin*
EDISON ELEC. INST.: *E. H. Dixon*
NAM: *C. G. Suits, W. Steiger*
ENGRS. JOINT COUNCIL: *R. Piggott*
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W. H. Zinn
A. M. Weinberg
E. P. Wigner
G. Weil
Sen. G. Malone
Casper Ooms
O. Ruebhausen
E. Walker

Revision of Act			Plant ownership by industry		Fuel ownership by industry		Patents compulsory licensing				Urgency of developing nuclear pwr		Who should be responsible for engg. & bldg. civilian power reactors?			Approach			
in favor	opposed	not opposed	yes	no	yes	no	against change	for change	for	against	great	slight	primarily gov't	primarily ind'y	gov't-ind-y	single-purpose	dual-purpose	small plants	full-scale plants
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*Did not testify this way, but indicated this position to NUCLEONICS. †Proposed compulsory licensing of patents of broad significance.
‡Long-term viewpoint. §Proposed compulsory licensing for 1-2 year period after revision of Act.

IN THE PAST YEAR the Joint Congressional Committee on Atomic Energy has shown an intense interest in industrial participation in the nuclear power field.

Last December, the Committee published a 415-page report on "Atomic Power and Private Enterprise." This past spring closed-door testimony was taken from a number of witnesses.

On July 31, the Committee completed six weeks of public hearings. Over 50 individuals representing 46 separate companies, groups and Governmental bodies were heard. In addition about 60 others were invited to submit statements for the record.

Because of the importance of these hearings to the readers of NUCLEONICS, the editors are devoting a large number of pages to an analysis of the testimony.

The "box score" on p. 11 is a summary of the positions of witnesses who appeared at the hearings. The attitudes noted were as interpreted from the actual testimony. Where there are question marks or blank boxes, the witness' position was not completely clear or he had no position. An entry in the "no" columns under plant and fuel ownership does not always mean that an individual is opposed to such ownership but in some cases that ownership is not necessary or pertinent to his position. In general, the positions shown for the witnesses are for the short-term picture but not necessarily for the long term.

The principal part of this analysis is the material on the following pages —pertinent excerpts from the testimony. These excerpts are arranged under twelve headings consisting of basic questions which must be answered in an evaluation of legislative revisions.

Only material directly related to the legal problems is included. Thus technical statements are omitted.

No attempt was made—because of space limitations—to include the viewpoint of every witness under each heading. Rather material was selected to give a cross section of important points made, especially where there was a divergence of opinion.

Over-all conclusions drawn from the testimony are:

...All witnesses recognized the paramount importance of national security in any consideration of revisions of the Act.

...All recognized the need for government control of health, safety and security

...All recognized the importance of continued AEC activity in reactor research and development.

...There was no question raised that nuclear power would one day be economically competitive..

...No great emphasis was placed on the effect a delay in changing the legislation would have on civilian nuclear power.

...No company indicated it was ready to make a substantial investment in this business if the Act is changed.

DEAN (right) and STRAUSS (AEC): We believe the attainment of economically competitive nuclear power to be a goal of national importance.

1. Is it important for this nation to develop civilian nuclear power? If so, when? Why? Will the U. S. risk preeminence in this field if we delay an aggressive development program?

There was very little disagreement among the witnesses and the members of the Joint Committee as to the importance of nuclear power to this country both for military and civilian applications. The hope was frequently expressed that we not let other nations beat us out.

¶ **DEAN:** We do believe it is imperative that we create a favorable atmosphere which will hasten the day [of economic atomic power] . . . It would be a major setback to the position of this country in the world to allow its present leadership in nuclear power development to pass out of its hands.

¶ **MILLS:** It would be contrary to American tradition to neglect to look to the future both with respect to our historical aggressiveness in pursuing new developments and the fact that conventional fuel may one day be less plentiful and more costly.

¶ **WEIL:** I believe that the urgency to develop nuclear power at this time derives from such considerations as national prestige; establishing leadership in the field of atomic energy developments; availing ourselves of the opportunity of counteracting adverse propaganda by positive means, advancing our abilities to promote the strength of the free world by offering technological aid to our allies who may have more immediate economic interest in nuclear power and assisting in raising the standards of living in underdeveloped areas; and finally by improving

ROWLEY (National Lead): We think atomic energy is going to a large commercial enterprise some day..a big enterprise. We would like to play some part in it.

KINGSTON (Sylvania): We have become nuclear component specialists..Such components could be..sold to the Government or authorized industry at a unit, competitive price.

STEVENSON (Allis-Chalmers): We'll solve the problems more quickly the sooner we get at them.

our ability to develop new sources of vital raw materials and making it possible to use more effectively the natural resources available to us and the free world.

¶ **WIGNER:** The ability to build nuclear reactors and to produce economic nuclear power is a national asset just as surely, and probably to a higher degree, as is our ability to drill oil wells, to produce gasoline, or to build and operate railroads.

¶ **WEAVER:** We must not lose the momentum of our current development program. I believe it would be a severe blow if we were to drop the type of development that we are carrying on today on reactors under the assumption that it can be picked up by inadequate facilities and inexperienced staffs of people.

¶ **ZINN:** I believe that if this country wishes to obtain leadership in this field a decision to proceed with a fairly large-scale power plant now is required.

Q. Cole: It is your thinking that the knowledge of the fact that this country is about to enter into a developmental stage of industrial nuclear power would facilitate negotiations for ore with foreign countries, with the belief that the knowledge that we might learn from this development would eventually become available to them?

A. Smith: I am inclined to think it would.

2. Who should develop nuclear power? Government? Industry? Government-industry?

Almost all witnesses agreed that the AEC should continue to play an important role on the research end of reactors. Almost all agreed that somewhere along the line private enterprise should be brought in. Some members of the Joint Committee prefer AEC to continue its contract method of operation. No one in industry said that this is the time for industry to take over lock, stock and barrel. The power and chemical industries are most interested in getting into the field now.

Q. Pastore: Who do you think should start building plants, the Government, private industry alone or a joint effort?

A. Dean: It looks as though the next four or five years would be a period largely of development . . . the building of reactor prototypes, experimental reactors . . . These prototypes will not be built with private money during the course of the next two or three or four years. Therefore, there is still on the Commission the burden of going ahead with an intelligent experimental reactor program. This, however, is not to say that in three or four years industry will not be prepared to go with large sums of private capital into very large reactors based upon designs tested by AEC.

Q. Holifield: Why not use the contract method to bring nuclear power to the point where it is economic and then turn it over to all American industry on an equal basis?

A. Dean: Because you have lost something in the meantime—the inventive genius of American industry, the competition in ideas . . . Then you start from scratch to get American industry in, and you have lost three or four years of their participation.

Q. Cole: From your observation of the Government's program and your understanding of our industrial private enterprise system, which, in your opinion, is in a better position to construct a power reactor with more likelihood of economic success?

A. Rabi: The influence of the power industry, which has to operate a reactor and make a profit, would be such as to make their point of view the more economical.

Q. Holifield: Your thought . . . is that you should be allowed to continue to cooperate and absorb the developments in Government reactors and laboratories as they come about?

A. Putzell: We envisage a partnership. We look at this as trying to get industry into its more traditional channels, and getting industry to put in some of its own skills, its own experience and money, to take some of the risk of loss, and to go forward in this field hand in hand with the Government.

¶ **GALE:** It would be a serious mistake if the entire atomic power program were to be turned over to private industry at this time. For example, how could private industry spend $100 million more or less on a power plant without any real knowledge as to the cost of the fuel? We should regard it as an equal if not greater mistake were private industry to be shut out of the program entirely;

we are confident that atomic power at competitive cost will be a reality much sooner if private companies participate.

¶ **ZINN:** The facts make the Government a partner in whatever development does take place:

1. The Government can never relinquish its control of fissionable material no matter where the actual ownership is lodged.

2. It is extremely unlikely that any reactor complex could be constructed without making use of many patents now held by the Government.

3. It is unlikely in the near future that any reactor design will be developed to the point of construction without making use of facilities now owned by the Government.

It is difficult, therefore, to see how any private group could obtain a monopoly in any part of this field. Certainly the Government would license the use of fissionable material, license the use of its patents, and make available its specialized facilities to any company which had a legitimate claim.

Conversely, I do not believe the Commission should attempt to go it alone . . . I believe the Commission and its contractors have a good record in using reactors to further our military position. Many times, however, cost has been sacrificed for speed or for a guaranteed performance by a certain date. What is needed now is experience in getting results in an area where cost is paramount. This experience the private utilities have. The application of this experience to the reactor problem, I am convinced, would be the greatest single factor in getting a competitive cost.

¶ **WEINBERG:** In the development of compact power reactors, an eminently reasonable course has been charted: namely, the Government, by contract with equipment manufacturers, has done the development required to demonstrate their feasibility. From now on, the equipment manufacturers presumably will supply these devices in a manner not essentially different from the way in which this is done for many other items of heavy equipment. Since the development was done at Government expense, the designs are available to all who wish to enter the field, subject to restrictions of the same type that surround any military equipment enterprise. I see no essential difference between this situation and the one which exists in the aircraft or ordnance manufacturing businesses.

An urgent case can be made for the Government assuming responsibility to develop inexpensive nuclear power—paying for and shepherding the development to the point where practical and cheap power plants are working. These . . . can . . . serve as working models for [industry].

The Government has at least as great a stake and interest in the development of cheap power as in compact power . . . Should any private group wish to go it alone, I think the Government should give it encouragement and support, but I believe it would be a serious mistake for the Government to consider any such private effort in any sense a substitute for the Government's own effort.

Q. Holifield: Do you not believe if the Government went ahead on the scale that you suggest here, and with the objective of producing cheap power, we would obtain that goal much quicker than we would by taking it up and putting it in the hands of individual enterprisers who furnish their own money?

A. Weinberg: I believe this is probably the case . . . I see right now an entirely or almost entirely bona fide aspect of the nuclear industry which can right now be taken over by private industry, namely, this small-scale aspect.

¶ **STARR:** What is the proper course for the nation to take? First, the program should be in the hands of those in industry and government whose primary concern is atomic power plant development and manufacture, with, of course, the over-the-shoulder participation of the eventual operators.

Second, as the real market for central station-size atomic power plants is several years away, and their development is a national asset, government support of a technical program leading toward their economic performance would be justified. Such support could be gradually removed as a real industry develops.

Third, the emphasis should be on small scale pilot plants. Several of these should be built now in order to investigate the most promising technical approaches. At a probable rough cost of 10 million dollars, or less, each, a half dozen or more could be built for the cost of one central station size plant.

If dependable pilot-plant size units could be developed, there might be a small but real market for such plants in special purpose or high cost locations. The atomic power industry, as yet unborn, might be brought forth in this manner. When the technological development of atomic power plants results in economically competitive power from such plants, a sound basis for industrial atomic power will have been established.

Q. Pastore: You believe that the objective of obtaining that successful reactor [a full-scale civilian power reactor] would be by continuing the present arrangement, in which the Government finances and in which private industry contracts and puts its best brains and initiative forward to obtain the results.

A. Weaver: I do.

Q. Pastore: Therefore, it is fair for me to assume that unless the government gets into the building of a plant, we are not going to have it.

A. Weaver: That is right.

¶ **WIGNER:** It would be a mistake to decide now either that the AEC should assume this task or that it should be left to private enterprise. Rather both types of institutions should be given an opportunity to participate in the program.

Competition will provide us with a measure of our success and make an effort toward such success worthwhile.

Several independent enterprises striving toward the same goal encourage an atmosphere which creates people who are dedicated to the purpose of economic atomic energy. In spite of some familiarity with the AEC

THEY ASKED THE QUESTIONS

For identification purposes, the members of the Joint Committee whose names appear in this analysis are: Rep. Cole, chairman; Sens. Hickenlooper, Pastore and Bricker; and Reps. Holifield and Patterson.

laboratories, I know of very few people who would be willing to devote the next twenty years of their lives to the problem of economic nuclear power. However, the program needs such people. It needs people who are willing and eager to start research on this problem and follow it through all adversities right down to the final conclusion.

Under the present arrangement, the ambition of the members of the national laboratories is more naturally directed toward proving themselves useful members of their laboratories—a very worthy purpose—than toward a specific technical goal. Also, it is not in the nature of government institutions to give economic considerations a dominant role.

Q. Pastore: What is your feeling with relation to the investment of public money in the development of atomic energy for industrial uses?

A. Raleigh: We feel that this is a transition program from an area in which it was practically all government money at one time, and because of the extent to which the Government is going to have to continue control of the industrial operations in this field, it would seem that the Government should be to some extent in partnership with the industries which will be making developments.

¶ **MORRIS:** The Atomic Energy Commission should assume the responsibility for carrying forward development of a pilot plant for production of electric energy from nuclear reactors.

Q. Holifield: It is your considered judgement, then, that if legislation were passed which would put these different groups of private enterprise into this project at this time, we could expect delay rather than acceleration of the time when kilowatt hours would be available.

A. Morris: That is our view.

¶ **SIGAL:** The CIO is firmly of the opinion that the AEC should never have begun this process of delegating its production responsibility [to industry under contract]. We believe that the public welfare demands public operation, as well as public ownership, of the atomic energy industry.

AEC should proceed without delay to build full-scale power-only reactors.

¶ **BIEMULLER:** While the AFL is anxious to see private initiative and enterprise participate more actively in atomic power development, we believe it would be a mistake to abandon or curtail government activities in the expectation that private industry can take over the whole job. Atomic power should be viewed as a national objective.

STARR (North American): From a technical standpoint, such large-scale plants are not the most expeditious path to economic power.

McCUNE (GE): So far, GE has not had, nor desired, a contract for the production of an economic power reactor. . . [Now] we should expand that effort [on industrial power].

CISLER (Detroit Edison): Nuclear power development is clearly a responsibility of competitive industry.

MILLS (Foster-Wheeler): Industry [will make] available at an earlier date benefits [from] competitive nuclear power.

WEAVER (left), PRICE (Westinghouse): We are convinced of . . the promising future of atomic power. Our experience makes us sharply aware of the mass of problems, but still firmly optimistic.

3. Should the Atomic Energy Act be revised? When?

The power companies and their associates speak out most strongly for revision. Equipment manufacturers did not press this point very hard. Labor is split: CIO was against revision, AFL was not opposed to it. Joint Committee members want to make sure the public investment is protected particularly insofar as patents are concerned.

¶ **SMITH:** The Department of State favors legislation which will hasten the day that atomic power can be made a reality . . . Development of atomic power is consistent with this Government's support of an effective system of international control which would prohibit atomic weapons by ensuring and promoting the use of atomic energy for peaceful purposes only.

¶ **CISLER:** We believe modifications of the Act are necessary to permit and encourage the participation of competitive industry using private funds in the development and application of atomic energy for peacetime purposes. In our opinion, these modifications can be made without relaxing the security provisions of the Act. . . . We further believe . . . that [this] development . . . is the responsibility of competitive industry.

Our belief, expressed in December 1951, that the development of a commercially competitive breeder reactor does appear to be feasible, has been strengthened by subsequent studies . . . We hope to undertake detailed design and construction phases before the end of 1954.

These companies [involved in our project] constitute a very substantial national resource, and we believe it will be possible to undertake privately the construction of the reactor and associated facilities. They possess the financial capacity, the economic incentive, and the organizational capability to carry out this project.

Those investing private capital in an atomic plant would need to know that they could have full control of the plant for its useful life. They would need to know that they could obtain the necessary atomic materials for fuel and could sell or dispose of fission products through the normal channels of commerce, subject to Government regulation in the interest of national security and safety.

¶ **PUTZELL:** We feel that one in industry cannot think very seriously about nor risk his money on the development of new applications of nuclear reactors so long as he knows that it is illegal to own the plant even if he should discover a novel and unusual way of using its nuclear heat and radiation . . . The net effect of the ownership restriction is to hamper this country's development of reactors.

¶ **WEAVER:** If, this time last year, you had asked us whether the present law is delaying atomic power development, we in all probability would have said we thought not. Today our view is changing because 1953 circumstances are different from 1952 in the significant respect that STR, the first nuclear power plant producing substantial quantities of useful power, is actually operating. We are now increasingly impressed by the need of mobilizing more minds and more resources for a broader attack upon atomic power problems.

¶ **ATWOOD:** In order to permit ownership and operation of a small industrial process reactor, the law does not require changes.

With respect to the ownership of large amounts of fissionable material and nuclear power facilities by private industry, we have no reason to feel that the time has arrived where a pressing need for such provision exists. We do feel, that, at the proper time, the law must be changed so that the development of this vital power source will not be artificially held back, recognizing at the same time that governmental licensing and security surveillance will always be required in the interests of national safety. Such a change lacks urgency at the present time, in our opinion, as a great deal more development work must be done before these large commercial installations can be confidently undertaken.

¶ **Hickenlooper:** There is no particular object in making a major change in the structure of this basic law unless some very substantial results by way of improvements and new developments can be expected.

But meanwhile it is entirely possible we could take the genie out of the bottle, and then could not put it back in again. It would be gone, and we would lose it. There are calculated risks that would have to be taken. I think if we could be sure, of course, that great results would come from this, that would be one thing. If we could be reasonably sure, that might be an inducement to change this law.

¶ **WEIL:** My view is that the Act should be amended

Where Do We Go From Here?

WASHINGTON (*McGraw-Hill Washington Bureau*)—Congress will take one more long look before it gets down to writing policy which will encourage the industrialization of nuclear power.

The real job of writing congressional policy on the role of private enterprise in the atomic power field will come next year. Chairman Sterling Cole of the Joint Congressional Committee on Atomic Energy has already set up an optimistic schedule:

- Legislation will be introduced in January proposing a number of revisions in present law along the lines suggested by the Atomic Energy Commission (NU, June '53, p. 88).
- Six weeks of hearings will be held on this legislation probably ending in late March or early April.
- By early May the final product should clear the Joint Committee and be ready for consideration by the full House and Senate.

Exact shape of the congressional policy will not be known until the Joint Committee reaches some agreement following next year's hearings. It appears, however, that Congress will move to give private enterprise additional incentive to develop and construct power-producing reactors.

But there is a possibility that Congress will move more cautiously. Instead of extensive changes in the basic law, it may confine its action to a general policy statement designed to encourage AEC to step up its present form of cooperation with private industry in the atomic power field, at the same time calling for a more liberal interpretation of the present Act.

Purpose of either of these moves is to bring the initiative and know-how of industry into the production of nuclear power.

To a few members of Congress, this is an urgent matter. One key member of the Joint Committee puts it this way:

"We are reaching the point where we are not worrying so much about our stockpile of fissionable materials for weapons. If we are to keep our production plants running, we must move at an increased rate to develop and produce nuclear power for civilian utilization.

"Under the present conditions (of government monopoly) the rate of research, development and construction is proceeding as rapidly as could be expected. The only sure way to step up the progress is to bring private enterprise into the picture."

This sense of urgency is not widely shared among the members of Congress. Except for a few members of the Joint Committee, Congress has largely ignored the complicated problem of bringing private enterprise into the atomic power field. There has been almost no reference to the problem in general debate in the House and Senate. Pressure of day-to-day legislative duties has kept average attendance at the long series of hearings down.

As the hearings closed, a heavy majority of the Joint Committee appeared to favor positive action regarding legislative changes. But the hearings also served to point up a sharp minority opposition to any relaxation of government control over nuclear power development.

Chairman Cole expressed the majority viewpoint when he told NUCLEONICS, "I am convinced of the probability of success of our efforts. I feel confident that Congress will make adjustments which will open the way for private capital to venture into the nuclear field—being fully assured that public interest can be completely protected by AEC administrative procedures."

Some members such as ranking Democrat Carl T. Durham go even further than Cole. They consider some relaxation of government control not only as necessary but pressing.

Opposition to any basic changes in the law is lead by Representative Chet Holifield, California Democrat. He calls the AEC policy statement "premature, ill-advised, incomplete and a clear evasion of AEC's responsibilities . . ."

Holifield does not believe a revision of the Act is of major importance in bringing private enterprise into the field. He believes this objective can be accomplished without relaxing government control over fissionable materials or facilities for using or producing such materials.

This general viewpoint is shared by Senator John O. Pastore of Rhode Island, another Democrat. There is a possibility that two or three other Committee members would side with Holifield if a showdown should come squarely on the AEC policy statement.

But chances are that the issue will not be drawn in such a rigid manner. The legislation to be introduced by Cole next January will likely include some of the AEC suggestions, but will probably be tempered to meet some objections of the present opponents. In any event, these opponents will have a hand in writing the measure that finally comes to the floor.

Before Congress takes any definitive action on the matter, Holifield is demanding that AEC submit a full and comprehensive report on the social, political, economic and international effects that any revision of the basic act would entail. Such reports are required, under the Act, whenever it is determined that civilian use of fissionable material or atomic energy has been developed to the point where it is of practical value.

In submitting its power policy statement, AEC concluded that the next few years should bring about such development. At this time, said AEC, such a report is not yet warranted.

If opponents of the revisions are able to make the demand for a report stick, they may well delay any significant changes in atomic power policy beyond next year. Such a report would take months to write and more months to process.

only if specific developments are in mind and only in relation to those anticipated developments.

¶ **ELLIS:** Every taxpayer and every consumer in the country has an investment in our atomic works. It is a vast, new public domain, as we see it, and this committee is its guardian, the Congress is its guardian. There is a fine law on the statute books. We cannot find anything wrong with the law.

Q. Pastore: When do you think we ought to proceed with the changing of the Atomic Energy Act?

A. Rowley: I would think now; the sooner, the better; providing the incentive would start the ball rolling.

¶ **FERGUSON:** Any healthy and expanding technology requires the steady influx of new people and the constant broadening of uses for its knowledge. This we now find restrained in the atomic energy field. The weapons program is substantial and rapidly improving but the rate of progress in peaceful applications under present law and policy is comparatively slow. If we are to interest new people and find new uses, we must have a breakthrough from present programs and restraints into the broader industrial markets. What may be the greatest of all technological fields warrants the widest possible participation of industry.

¶ **MORRIS:** The controls on the use of fissionable materials which are contained in the Atomic Energy Act of 1946 should not be released until adequate knowledge and information are available with respect to the use and development of atomic energy for industrial purposes and production of electric energy. If and when such controls are modified, adequate provision should be made to prevent any monopolistic advantage accruing to private persons or corporations, through operation of the patent laws, or otherwise.

¶ **SIGAL:** The burden is upon those who would amend the Act to demonstrate that their proposals would achieve the objectives [of the Act] more effectively than the present law would permit. In our opinion they have not made, nor can they make, such a demonstration.

We think there is no reasonable basis for asserting that the Act, in its present form, does not permit the widest possible development of the potentialities of atomic energy.

4. How important is question of plant ownership? Fuel ownership?

Once again there is a difference between the attitude of power companies and that of equipment manufacturers. The former favor ownership, the latter say it isn't too important. What all agree on is the need for a clear statement of limitations imposed upon use.

Q. Cole: Do you feel it is necessary at this stage of the game for a private company to have the right of ownership of the fissionable material, or is it sufficient for our purposes simply that he should have the right to use it under license with the ownership of the material remaining with the Government?

A. Mills: You probably could accomplish the same results by either method. But I believe you would get along faster and make more progress if you changed that law to permit, under proper national safeguards, [private] ownership. I say that because I believe you have a better interest from the standpoint of the commercial approach by industry to these problems if they realize that they have something that they are responsible for and which is their property.

Q. Cole: I have in mind particularly the policing, whichever method is used—whether by way of leasing the material or granting outright ownership—either way involves a great amount of accounting processes and security surveillance and I wonder if it would not simplify those aspects of the problem if we were not concerned with the question of ownership.

A. Mills: I do not believe so. I rather believe that there might be a benefit that would accrue from the other side of the picture, and that is that you can set up standards of security and accountability that you desire, and you can make industry responsible for carrying that out and policing it . . . I do not think there are any security regulations . . . that cannot be administered by industry.

¶ **WEAVER:** As potential sellers of atomic machinery, our concern with possible changes in the law to permit private ownership of such equipment is less direct and primary than that of purchasers and users.

Q. Holifield: Why in your opinion would ownership of fissionable material by private sources be more desirable than the utilization through a lease basis with the government?

A. McCune: I think the man who operates a plant feels he has complete responsibility. That can be equally so if he rents the plant. But I would expect a man with a rented facility would certainly move more cautiously than the man who owned the plant.

Q. Holifield: I can not see where actual ownership of the material itself would be a primary factor in further development.

A. Iddles: No, the fundamental thing is the right to use it up for useful purposes.

¶ **SIGAL:** If this government should adopt a policy that would permit private industry to own and produce fissionable materials in substantial quantities, it will thereby give notice to the world that we have retreated from our determination to abolish atomic weapons by international agreement.

5. If the Act is revised, are changes necessary in the patent provisions? How about compulsory licensing?

This is the most controversial issue. Industry wants normal industrial patent procedure as it relates to a military field. Congress appears to favor compulsory licensing. A compromise may have to be drawn.

¶ **DEAN:** We have specifically stayed away from any suggestions as to how you answer the patent question. We have not suggested that the law be changed. We have suggested simply that probably during this interim period the Commission should, as a matter of Commission policy, but known to the Congress, liberalize its interpretation of the patent provisions of the Act.

¶ **RABI:** If the influences [of public demand and commercial competition] are permitted to operate in the field of nuclear power, the nuclear power industry would become

an important component of our American economy in the next 25 years. Nuclear power in the foreseeable future will have very strong competition from conventional power, and we therefore do not have to fear that a strong monopoly would be set up in the power industry through the possession of some basic patent or secret process. There are many different designs which are possible, and it is not likely that any one would have an overwhelming advantage.

¶ **GILLESPIE:** We favor opening patents to all the world . . . The greatest profit comes from a broad licensing basis. Let anyone come in at the lowest possible royalty rate. Your broad field of patent licensing gives you the income, rather than holding it to the restricted view and charging a high rate.

Q. Holifield: If you want complete widespread participation in the benefits of atomic energy . . . and if you want the widest possible competition . . . you wouldn't object to a compulsory licensing system?

A. Gillespie: I would feel very strongly that we shouldn't put a compulsory licensing clause in the Atomic Energy Act, for the reason that it should be made as near like the patent provisions of the general business world today as possibly can be had.

¶ **MILLS:** What we are interested in from the patent clauses are the new ideas that are developed as a result of what has already been developed by the Government. We feel that there should be some protection on that basis along the same lines as we recognize individual and company rights with respect to such ideas as are developed.

¶ **GALE:** I do not think that patents have played a very great part in the development of a private utility industry.

¶ **COHEN:** We propose that Section 11 on patents and inventions be amended to permit more nearly normal patent rights in the field of nonmilitary utilization of atomic energy. As a matter of procedure, we feel that it is desirable to permit patents to be filed on both military and nonmilitary uses. The Commission would be authorized to requisition or condemn any inventions in the fields of production of fissionable materials and weapons, and to acquire by purchase any patent in a nonmilitary field. Holders of all patents would be required to tender to the Commission a free license under such invention for all governmental purposes, and compulsory licensing of patents of broad application is provided for.

¶ **McCUNE:** We believe that patentable inventions relating to the field of atomic energy should be on the same basis as patentable inventions in other items of highest importance to the national defense, and in this connection that in contracts between the government and private contractors, the patent clauses in such contracts should conform to existing practices prevailing in the Armed Services procurement regulations.

¶ **ELLIS:** It would seem to us very harsh, to permit patents, exclusive rights, which would lead to monopolies, which would tend to cut off the smaller industries, chemical industries, power industries, including the electric co-ops. That is what we fear, at least.

Q. Cole: It is only through refinements of existing patents in the nuclear field that you seek to have patent protection?

A. Iddles: That is correct. If, by some long chance, we should discover a fundamental patent, the Government might very well say, "Well, that has to do with the defense,

COHEN (Kidde): Many designs must be made, many discarded, and many tried if we wish to progress to commercial atomic power.

MENKE (NDA): A strong competitive civilian nuclear power industry should have a production capability..which will eventually be..say ten times greater than that of the Government arsenal today.

WEINBERG (ORNL): I am a homogeneous reactor man..we can ultimately make 5 mill power..a breeder.

SIGAL (left), SWISHER (CIO): We believe the public welfare demands public operation, as well as public ownership, of the atomic energy industry.

and in any event it is secret, because we do not want a foreign power to have it." The right to deny us the use of that would be paramount, I should think. But it is not likely that we will invent a fundamental improvement.

Q. Cole: I would like to have your thought on the effect of relaxing the patent provisions to the extent of permitting an inventor to have the exclusive right to his invention for any purpose in this country, but requiring of him that he release to the Government the ownership of that patent so far as its uses in foreign countries are concerned.

A. Ferguson: As an intermediate step, I think it has good possibilities. In the later stages of it, in the commercial aspects of it, I think we would have to recognize that any commercial enterprise of our country has broad foreign investments, frequently, broad foreign associates, to make the most of the commercial product available abroad.

¶ **MORRIS:** If private expenditures are to be made for this research work, it should be specifically provided that no patents will be issued to foster or permit a private monopoly.

¶ **DIXON:** Just in general, of course, the utility industry as an industry has no deep traditional feeling toward patents. Offhand I can't think of a utility company that of its own owns a patent. We are deeply concerned that the manufacturers are protected, the people who provide us with materials and supplies, because we find that when they develop a process they make it available, they want to sell it. If it will help us to generate electricity cheaper, if we can provide better service, we have a very great concern that they have every incentive to do these things.

¶ **OOMS:** Now, that the Government monopoly in the production and utilization of atomic energy is to be surrendered and industry drawn into the program, every incentive and encouragement must be given to enlist the participation. The patent provisions must be modified and atomic energy brought within the normal operations of the patent system to the fullest extent that is now possible.

In my draft, there is no automatic licensing even though the Commission declares the patent affected with "the public interest," but that each applicant for a license must demonstrate separately that the license is necessary to effectuate the policies and purposes of the Act. This restriction is maintained to make the invocation of this licensing power an exception and an infrequently used device. It is intended to guard against the fear that the inventor who is willing to devote his resources to making developments in this field would be compelled to share his contributions with his competitors and to insure that he will be required to give licenses only in the extreme and infrequent situation where it is necessary to accomplish the designs of this legislation.

This provision is designed merely as an interim measure during the transitional period when general participation in the program is not feasible.

I have no use whatsoever for a general compulsory licensing scheme.

Q. Holifield: Why should any restrictive patents be given during this interim period?

A. Ooms: The objective that I think every industrial witness that has appeared here has expressed is a desire to get into this on a normal industrial basis.

There is one thing that our patent system has done, we think, most frequently, on the restrictive aspects of it—but that has a blessing to it, too, in that if you give one inventor a patent upon one way of doing something, if people want to compete with him, they have to devise an equally good way to do it. The patent system works what some of the authorities call a compulsory diversification.

I have, in the twenty-five years I have been in this business, seen only one or two patents for which no immediate alternative was available. There have been a couple. But in every field, as the progress develops, a patent that may seem to be dominating tomorrow may be obsolete three years from now.

¶ **STEIGER:** Under existing law, an inventor may file a patent application in the U. S. Patent Office but that application cannot issue as a patent if, in the opinion of

the Government authorities, its issuance would be detrimental to national security.

The security laws with respect to patents generally have proven adequate, so where is the necessity for a different law with respect to patents in the atomic field?

¶ **KINGSTON:** It is suggested that a one or two year interim period be provided in the Act whereby a license to all patentable discoveries and inventions is made available to the Government, which, in turn, can sublicense qualified firms wishing to enter the field during the interim period. After the one or two year period, standard patent law should apply.

6. What would effect be on development of civilian nuclear power if there is a delay in revision of the law?

This, perhaps one of the most important questions for industry to answer, was touched on only slightly. Congress wants to know why the law should be changed *now* if industry isn't yet ready to spend its own money.

¶ **FERGUSON:** Until a policy [to encourage industrial participation] is decided upon each passing day is a day added to the years before atomic power can be "on the line."

¶ **CISLER:** If we assume that our studies will be completed in 1954 and that we conclude that a trial installation should be built, then we should be in a position to proceed with the next steps, detailed design and construction, without delay. In order to proceed with these, we should need to know that the financing is complete and that money is available for the entire construction program.

Obviously many problems must be met in undertaking such a venture, and a substantial amount of time, probably a year or more, will be needed to complete negotiations. If we are to meet such a schedule, law modifications are essential in the near future. Of greater and more general importance, however, is the need to attract additional private participation and investment in research and development. This will come slowly at best, but will not begin until the way is cleared by law changes. If we agree that competitive industry should participate more widely in atomic energy development, then there is no tenable reason for postponing the law modifications which will make that participation possible.

7. What would effect of developing civilian nuclear power be on international control?

The only authoritative answer on this could come from the State Department. It sees only good from a strong power program.

¶ **SMITH:** It is of paramount importance to our international relationships generally that the U. S. maintain and improve its leadership in atomic energy development . . . It would be very damaging to the position of the U. S. if another country were to be first in this field; and it would be especially damaging if the Soviet Union were to precede us in the development of atomic power. If this were to happen the Soviet Union would cite their achievement as proof of their propaganda line that the United States is interested in atomic energy only for destructive purposes while the Soviet Union is interested in it for peaceful purposes.

On the positive side, by being the first to develop nuclear power, we will have further demonstrated to all the world that we are intensely interested in the peaceful aspects.

The safeguards of the UN [international control] plan closely parallel those provided in our existing domestic legislation . . . If, in the course of developing a domestic program of nuclear power, we acquire experience which would call for modifications in our position on international control of atomic energy, we would not hesitate to modify our position accordingly . . .

BIEMILLER (AFL): AFL is anxious to see private enterprise participate more actively . . [but] it would be a mistake to abandon or curtail government activities.

We must at all times be prepared to enter into an arrangement no less effective than the UN plan for international control. Therefore, I strongly urge that any [new] legislation take this into account.

8. Is money now available for an aggressive civilian nuclear power program? From government? From industry? If not now, when?

At the present, neither the Government nor industry has said it will spend the money needed for building power reactors. In most cases, industry says it is not yet in a position where it can determine this.

Q. Pastore: Mr. Raleigh, do you think that changes in the basic law would encourage private industry to invest more money in the development of atomic energy for industrial uses?

A. Raleigh: Yes, Senator, I know, as a matter of fact, that it would, and I know that there are cases which have come to our attention where there is hesitancy at the present time, and that hesitancy would certainly be eliminated by revision of the Act.

Q. Pastore: Do you feel if the law were amended you would invest more money in these experiments?

A. Rowley: When the right opportunity arose, yes. I think if the National Lead Company felt that there were a profitable enterprise having to do with the manufacture of

fuel elements, and we were allowed to gain patent rights from some of our developments, those that came after the work we are doing now, those that we are doing now for the benefit of the Atomic Energy Commission, we could supply to someone interested in manufacturing power a reactor fuel element at a lower cost to them, at greater advantage to them; then we would be willing to invest in such enterprise.

Q. Holifield: How much money is Monsanto prepared to put up?

A. Putzell: I can't answer that today . . . As you know, the chemical industry has a reputation for raising money and developing and growing with that new money.

¶ **WEIL:** Assuming, and I believe this is true, that the nuclear power industry in this country should in the long run be developed by private enterprise, can we expect that by turning the responsibility over to this group now, private risk capital will support the aggressive construction program that should be undertaken? In my opinion the answer is "no."

To obtain and retain financial support from public sources now and in the foreseeable future a project must have either a high military priority or at least noncontroversial goals in the national interest. A project to construct a single purpose nuclear power plant has neither.

It is not difficult for me to imagine that a government project initiated today with the single objective of producing power for civilian or industrial use would have its objective changed to provide power for an aircraft carrier at some later stage in its development.

It is my conviction that such a project would have a small chance of survival during the next four or five years required for its completion, if the major fraction or all of its financial support is derived from public funds.

I believe that here may be a solution, namely, enlisting the financial support of private nonprofit organizations.

Q. Hickenlooper: If the law were altered at this time to permit private companies to go into this field independently on their own, do you think Allis-Chalmers would be prepared to spend a substantial amount in experimentation and research and development on their own?

A. Stevenson: I could only answer that by citing what we are starting to do, within the limits of the area in which we can operate. And that is that, as you probably know, we have joined with a group of some eighteen power companies and four other industrial firms with the avowed purpose, within the law, of trying to build a reactor to produce electrical power.

¶ **BROWN:** As a general policy, the American Machine and Foundry Company has for years invested in long range developments and has expended considerable money and effort on new programs [aimed at] future profits.

We would like to look forward to making similar expenditures of money and effort in the industrial atomic energy field in the early 1950's, and we are prepared to do so under appropriate incentives.

¶ **WEAVER:** Westinghouse recently reached a decision which, so far as we know, commits more private money to the future of atomic power than any other company has yet determined to risk.

If you were to inquire whether Westinghouse might consider putting up its own money to construct such a plant, we should have to say "no." The cost of the plant would be a question mark until after we built it and, by that sole means, found out the answer.

The amount of money which Westinghouse could itself appropriate to meet the situation would be but a trickle compared with that required.

9. What Government financial support might be necessary for an industrial program?

One industry group has said it will not require Government support. Others want guaranteed markets for by-product plutonium. AEC originally opposed the latter but now is leaving the door open to it. Some say importance of starting an industry warrants subsidization.

¶ **STRAUSS:** I am not prepared to rule out the possibility of plants designed to produce weapons-grade plutonium as a byproduct. I am aware that such plants might involve compromises in design which would qualify the usefulness of power cost from them. I am assured, however, that the Commission's power policy statement was not intended to preclude such dual-purpose plants, so much as to emphasize the greater desirability of plants which are economically justified in terms of power production alone.

Q. Holifield: I assume that you would want contracts with the Government to purchase plutonium [which you would produce]?

A. Cisler: We are not seeking any contract, any guarantee, for the purchase of plutonium on the part of the Government. It must find its place in competition with the Government's own production of plutonium . . . [In addition], it is possible that, as a premium fuel for power generation in remote areas where fuel costs are high, it could be used.

Q. Holifield: You would not require any form of subsidization in the form of abnormal tax amortization or long-term Government financing at low interest rates or contracts for the purchase of plutonium at fixed prices?

A. Cisler: No.

¶ **CISLER:** If the AEC should decide that there should be a charge made for work [done at the national labs], then industry would have the alternative of meeting that expense or seeking other similar facilities to carry on the work.

Q. Holifield: Your participation, I believe, is contingent upon the sale of plutonium to the Government. Would you want a fixed price over a period of years for the plutonium?

A. Putzell: We think now is the time to get into . . . atomic power. The quickest way we have been able to find is a dual-purpose reactor, which involves the plutonium sale as well as the power production. . . . If, on the basis of a contract with the Government, . . . Monsanto went out and raised many millions of dollars to build a plant, there ought to be some fair degree of assuredness in the relationship with the Government, so that if the Government did cancel its contract shortly after the thing was set up, those who invested their money in it would not be just sitting there without anything . . . This suggestion . . . is based on the assumption that there is a decision made by the Government that it needs plutonium in the national

interest. If that need does not exist as a national policy, then this suggestion we made is without foundation.

Holifield: Of course, that need does exist, but we do not know how long it will exist nor how much of it we will need.

¶ **ZINN:** A generating cost of 10 mills/kwh and an assumed selling price of 7 mills/kwh requires a yearly subsidy of $2–3 million. The experience gained in operating such a plant could easily be worth this sum of money. Further, it would be possible to convert such a reactor to a plutonium production unit.

The subsidy indicated would not seem to be an excessive price to pay in order to get a new business started. Once established as a practical and useful operation, it will bring about its own improvement.

¶ **STARR:** I think if you want to put this field on a basis that is not Government-supported, what is going to have to be demonstrated is the competitive privileges of power from nuclear plants. Until such demonstration takes place, I believe Government support of one sort or another is going to be required. If the Government wants full-scale plants built, it is going to have to support this.

My own feeling is simply that the Government should pay for the manufacture of knowledge, but should not subsidize the manufacture of power. We feel that Government support in the manufacture of knowledge is a justified thing.

¶ **BIEMILLER:** In view of the fact that the nation has large hydroelectric resources still undeveloped and coal or other fuels in relative abundance, a serious policy question arises whether atomic power should be accelerated by subsidy incentives to private industry. It is our view that private enterprise in atomic power should be self-supporting and independent.

10. What would effect of a large-scale civilian power program be on national security as far as protection of secret data is concerned?

This was not given as much a play as expected, probably because industry has satisfactorily maintained security in its operation of AEC plants.

¶ **BECKERLEY:** There is no doubt in my mind that an expansion of industrial and public participation in the development of nuclear power can be accomplished without adversely affecting the national security.

¶ **RABI:** I do not think we are at the point where most or all of the information necessary to construct a good economical reactor can be given without security restrictions. Private industry that goes into this field will have to learn to live with such security restrictions. However, they have had a lot of experience in it. A large fraction of industry of the U. S. has worked under security.

11. How do we protect public investment and interest in civilian nuclear power? What about the interests of small business?

Considerable emphasis was placed on this in the questions. Some in industry maintained that the public has already gotten its return from its $12-billion investment via military security. Others said existing laws protect the interests of small business.

Q. Pastore: How would small industry be protected?

A. McKay: I would not think you would wish to issue an exclusive patent to any special group because this is a program developed by the Federal government with taxpayers' money, and I think any benefits which come by a peacetime operation should be given freely under the proper supervision to those who qualify.

Q. Patterson: Could you tell me how the smaller companies would have an equal opportunity?

A. Gillespie: The smaller companies are joining in our study group. We have electric companies that are small . . . very small. And there may be the possibility that at the core of most of these study groups you will find a group which is more expert and has had more experience in this field. But each project has gathered in new companies.

Q. Pastore: How do you give this monopoly that belongs to all the people to all private industry on an equal basis?

A. Putzell: In the manufacture of an airplane [for example], there are an awful lot of small manufacturers who

PIGOTT (EJC): Maximum engineering advances will be obtained by establishing in the atomic energy field the normal freedom for an engineer to publish.

SUITS, STEIGER (NAM): There will be an increasing participation on the part of private industry. . that will increase as the goal comes nearer.

RUEBHAUSEN: I question the fairness..of [limiting] access to atomic knowledge to relatively few.

OOMS: Our patent system works what some authorities call compulsory diversification.

make plastic parts, who make the paint that goes in it, who make all sorts of supplies and components which go into the airplane made by the large company . . .

It seems to me that a lot of the other processes of Government are going to be brought to bear. For example, the antitrust laws; maybe they should be adjusted in this case, and maybe not, but the doctrines of the antitrust principles are going to be one of the policing forces. The tax laws are another policing force.

Q. Pastore: I just want to say this that I am for this idea of having private industry participate in this, and I believe it is in conformity with our whole concept of free enterprise. The thing that is bothering me is how you pass the benefits on to all the people.

A. Bricker: I think we should look at the long pull rather than deciding all the questions at the beginning.

¶ **COHEN:** We feel that there is a place, and indeed an indispensable place, for businesses in the atomic energy field which at least start small.

¶ **ELLIS:** Nonexclusive licenses look good to us. Why shouldn't they be nonexclusive? Why shouldn't the American people continue to have a great vested interest in the program? It is still the public domain. The licenses would then be as free to one as the other. To grant exclusive licenses would be to narrow the field and to cut out many, many industries, including, we fear, many, many producers of power, the smaller ones.

¶ **IDDLES:** We believe the taxpayers' expenditure has been primarily a military investment and, as such, we have already received the benefit in terms of national security at a critical period when equal security was unobtainable by other than atomic weapons. In the development of atomic power, we believe that the taxpayers' best interests lie in the direction of minimum power costs. We confidently believe that costs will be less if industry is allowed to participate on a competitive basis and, furthermore, this will undoubtedly result in many new jobs being made available. We further believe that the development of atomic energy for power and other purposes will result in improvements not now fully conceivable and will be of such benefit to the people of the United States as to ultimately make the Government expenditure to date minor by comparison.

¶ **OOMS:** We have a widely expressed fear that, inasmuch as participation in the development of civilian atomic energy applications cannot be universal because of the limitations of necessary materials, the scarcity of competent technical men, and inevitable security problems, the select group that may be enlisted in the early stages of this work may derive an unconscionable advantage and actually secure a monopolistic position that will embarrass the program forever. The temptation to exaggerate this latter is great.

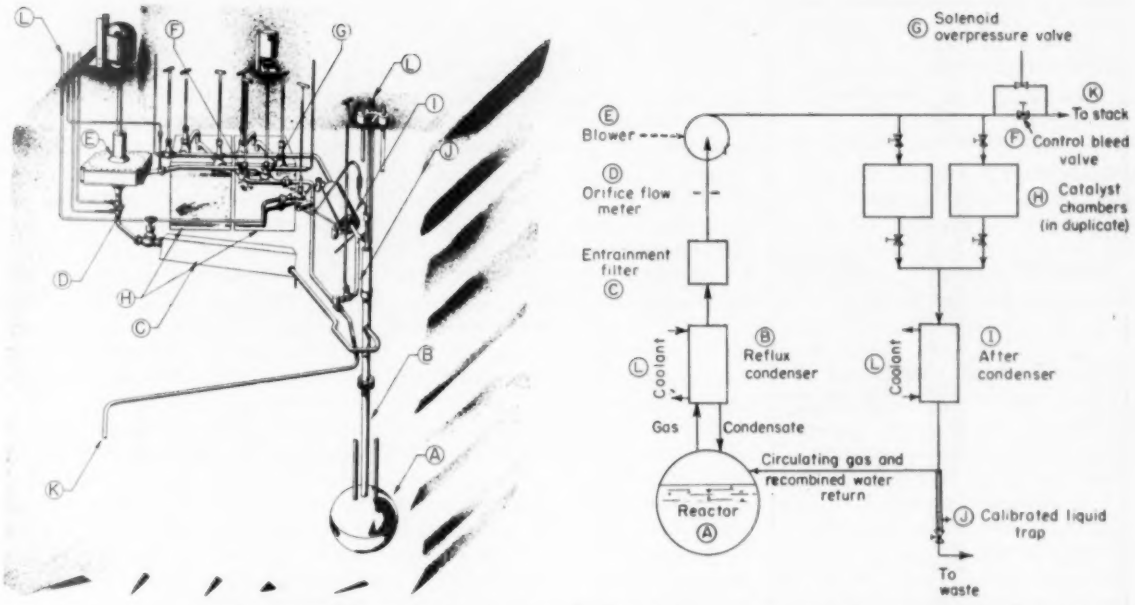
¶ **BIEMILLER:** Atomic energy itself and technology arising out of nuclear fission must remain in the public domain. While development of private investment and enterprise for civilian use of atomic energy should be encouraged, such use of it by private enterprise should be strictly competitive. Private monopoly in any phase of the atomic energy industry is intolerable.

12. Can we have an aggressive civilian nuclear power program which would be compatible with military requirements?

The military say yes.

¶ **LeBARON:** The Department of Defense expresses its strong support of a long range and vigorous program for the application of atomic energy to industrial purposes . . . We believe that private industry . . . will serve the nation to best advantage in the development of atomic power . . . We recognize that a vigorous and extensive atomic power program may have a pronounced effect upon the availability of fissionable materials for military use.

We believe that there can be an aggressive industrial program and a satisfactory resolution of the needs of that program for fissionable material with the weapons needs.



1 RECOMBINATION SYSTEM in phantom view and block diagram. Reactor off-gas is cooled in reflux condenser. Condensed vapors, de-entrained liquid drain back to reactor. After filter removes residual entrainment. Blower circulates 100 liters/min; manifold, vented to stack, leads gas to either catalyst chamber. Gas heated by recombination in catalyst is cooled in after condenser to reduce heat load on reactor coolant system. Calibrated trap in return line can be dumped to waste when desired

Gas Recombination System for a Homogeneous Reactor

Dissociation of the fuel-carrying moderator in the Los Alamos water boiler was one of the factors limiting it to low-power operation. The system described here has operated satisfactorily at powers up to 35 kw for two years (80,000 kwh)

By L. D. P. KING, R. P. HAMMOND, J. A. LEARY, M. E. BUNKER, and W. R. WYKOFF
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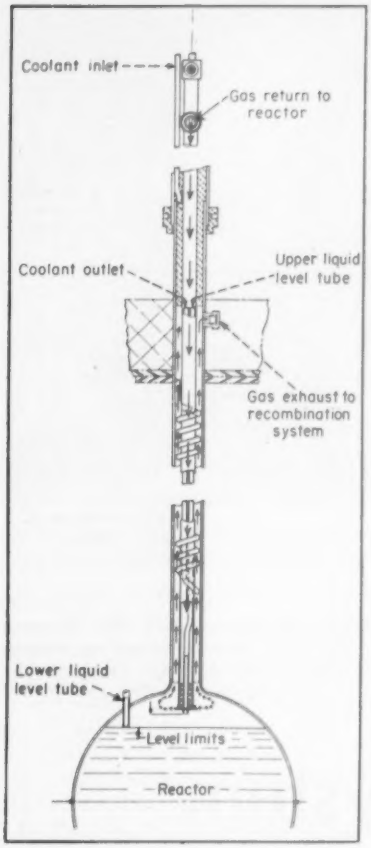
Los Alamos, New Mexico

THE LOS ALAMOS WATER BOILER is the first reactor in which fission fragments are released in the moderator itself. Other reactors using liquid moderators have had only ionizing radiations in the form of neutrons, beta rays, and gamma rays in the solution. In the case of the water boiler the large energy release in the fission process causes considerable additional decomposition of the moderator as well as a great increase in the radioactivity of the released gases.

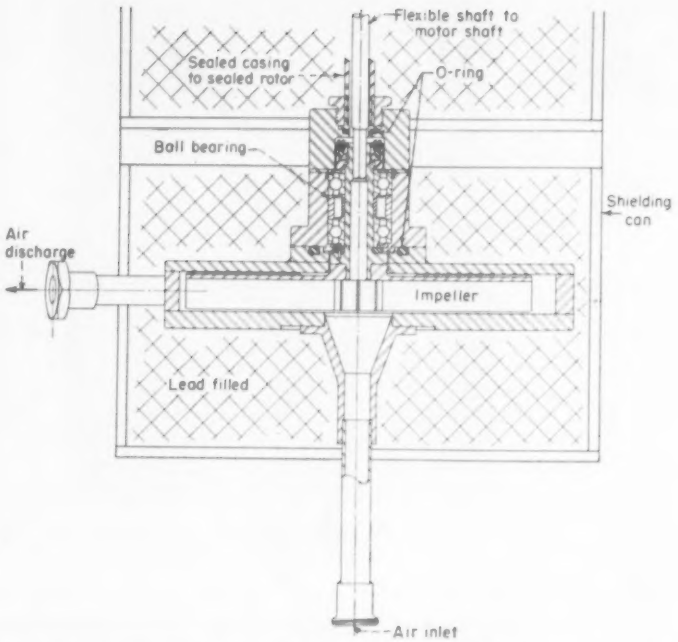
Operation of the early Hypo model† of the reactor at a specific power of 0.4 kw/liter of solution made it evident that it would be advantageous to recombine as many of the dissociated products as possible. This would reduce the changes in solution composition during operation and simplify the disposal of the remaining radioactive gases.

When the reactor was modified for higher power operation, provisions were made for the installation of a gas control system. Initial operation of the present Supo model‡ at a specific power of 2.4 kw/liter of solution indi-

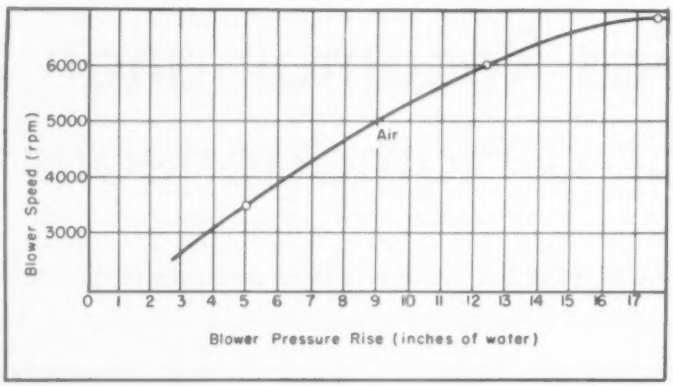
* Operated for the U. S. Atomic Energy Commission by the University of California.
† *Rev. Sci. Instr.* **22**, 492 (1951).
‡ LA-1301.



2 REFLUX CONDENSER UNIT has cooling-coil helix pitched so that condensate drains freely into reactor sphere. Gas from after condenser returns to sphere through ¾-in. central tube, is deflected by disk at bottom to sweep over solution surface with minimum surface disturbance. Circulating and off-gases then pass upward over cooling coil made of single 15-ft length of ¼-in. O.D. stainless-steel tubing. Cooling water flows counter-current to gas flow. Bubbler lines define reactor solution limits. Solid stainless-steel piece at top of condenser acts as a radiation shield, blocks rise of radioactive gas



3 BLOWER ASSEMBLY uses canned-rotor motor that eliminates need for a gas seal. Blower bearings were designed for easy replacement



4 PERFORMANCE of blower for gas flow of 100 liters/min. At 4,720 rpm, pressure rise is 8.2 in. water for air, ⅕ of this for helium

cated the advisability of installing a recombination system as soon as possible. The solution decomposition was as high as 4.5 cm³/min at 80° C. This represents a hydrogen release of almost 8 liters/min.* In addition to this potential explosion hazard, frequent solution additions were required to maintain satisfactory reactor performance. The large volume of highly radioactive gas also made it difficult to maintain satisfactory backgrounds at all times on counting equipment in the neighboring technical areas.

* Gas volume measured at an altitude of 7,000 ft, 23 in. Hg barometer, 25° C.

This article describes the equipment and initial tests of a recombination system installed on the reactor in February, 1951.

Design Criteria

Two methods were available for effecting the recombination of hydrogen and oxygen in the reactor off-gas: flame combustion and contact catalysis. A flame combiner would have the advantages of low pressure drop and unlimited lifetime, but since the water boiler is operated at widely varying power levels with frequent shutdowns, it appeared that steady operation of a flame combiner would be difficult.

Platinized catalyst materials of high activity for the hydrogen-oxygen reaction were commercially available on either charcoal or ceramic support. Previous experience indicated that repeated heating and cooling of charcoal material tended to produce fines that would plug the bed. The ceramic support was therefore indicated.

The water-boiler off-gas stream is not pure hydrogen and oxygen, but carries gaseous fission products, water vapor, and small amounts of entrained reactor solution containing uranyl nitrate, fission products, and free nitric

acid. The possibility of catalyst poisoning and bed plugging from these materials had to be considered.

Laboratory tests of platinized alumina pellets in electrolytic gas streams containing water and nitric acid vapor showed high catalytic activity except for a temporary loss when the pellets were actually wetted by condensed water. The effects of radiation and fission products could not be studied within the allowable time, so it was decided to proceed with a design that would at least minimize such effects. Design criteria were set as follows:

1. A rapidly circulating gas system to keep reactor and stack line below explosive concentration of hydrogen.
2. Removal of as much entrained liquid as possible from the gas stream, and return of it to reactor solution.
3. Cooling of gas leaving reactor to minimize nitric acid evaporation.
4. Use of a large quantity of catalyst to minimize poisoning effects.
5. Use of two separately valved and separately removable catalyst chambers, so that the second could be exposed to the gas only upon the exhaustion of the first.
6. Instrumentation to detect any change in flow or resistance of the system and to indicate the active zone of the catalyst bed itself. A progressive movement of this hot zone would indicate progressive catalyst poisoning.
7. Incorporation of an internal heater in the catalyst chamber to preheat the catalyst and drive out condensation on start-up, if necessary.
8. Condensation and return of recombined water to the reactor, with provision for diverting known quantities of this water to waste when desired.
9. Use of a gas-sealed shaft and an external, readily serviced drive for a circulating blower that provides a sweep-gas rate of 100 liters/min with a pressure rise of 8 in. of water.
10. Operation of the system at slightly below atmospheric pressure to prevent gas leaks into reactor room.
11. Construction of the entire system of type 347 stainless steel. Earlier experience indicated that this metal was highly resistant to corrosion by nitric acid and that welds could withstand corrosive action indefinitely.

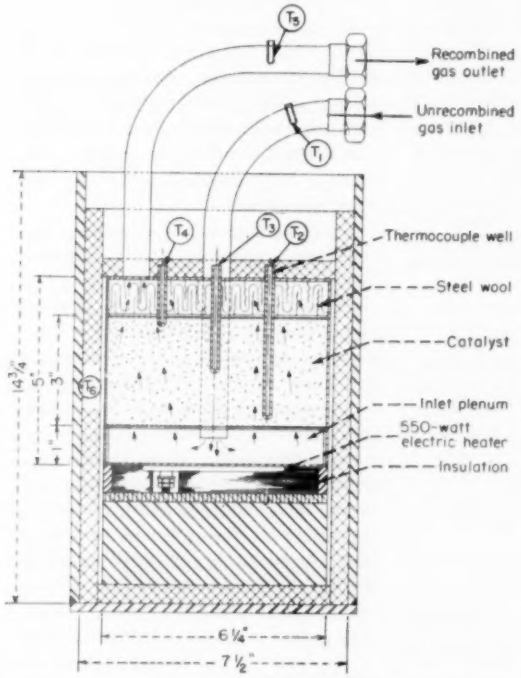
Layout and Components

A phantom view and block diagram of the circulating gas system are shown in Fig. 1. The reference pressure for the system is that in the stack to which the manifold is vented. A blower in the stack holds the maximum pressure in the system to 3 in. of water below atmospheric.

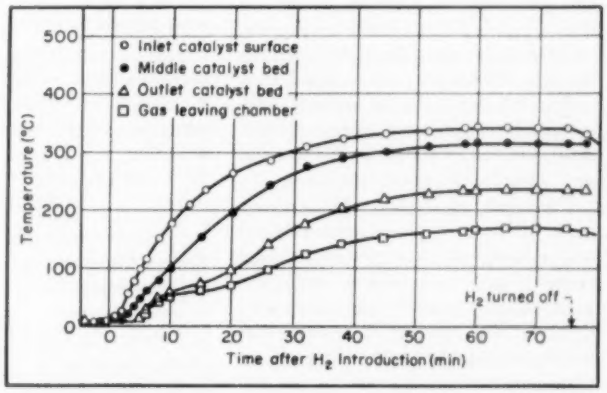
A more detailed description of the various components of the system is given in the following paragraphs. All intercomponent piping is of $1\frac{1}{16}$ in. I. D. stainless-steel tubing, with either a $\frac{1}{32}$ or $\frac{1}{16}$ in. wall thickness.

Reflux condenser unit. The major design consideration for this unit was that it cool the sphere exit gas from about 75° C to below room temperature. It also had to fit into the existing stack mounted on the reactor sphere.

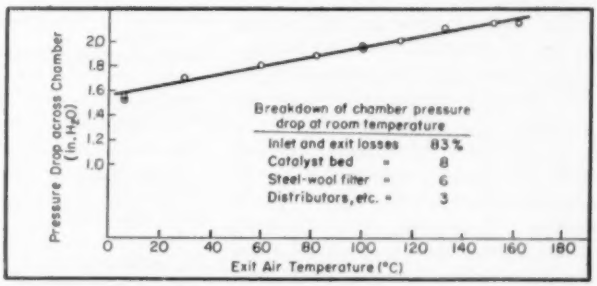
Details of this unit and a description



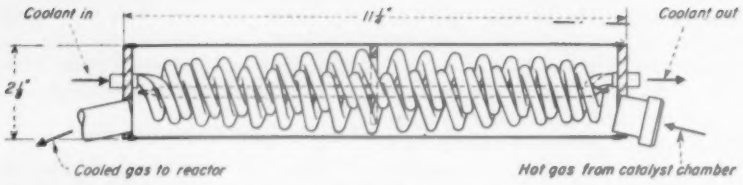
5 CATALYST CHAMBER is rectangular can with dimensions shown, $6\frac{7}{8}$ in. deep inside. Inlet gas is preheated as it passes through catalyst bed via central tube. Gas is distributed through a perforated plate, flows upward through 1,700 gm of catalyst supported on 18-mesh screen. Stainless-steel wool in exit plenum filters gas. Thermocouples measure gas, catalyst, and container temperatures. New catalyst gives maximum temperature at T_2; catalyst is considered spent when T_3 is less than T_4



6 TEST CURVES for catalyst chamber. Mixture of 4.70% H_2, 2.5% O_2, 92.8% air passed through chamber at 100 l/min. Apparently thermal equilibrium was attained 1 hr after start of hydrogen introduction. Inlet side of bed attained highest temperature; most of reaction occurred in this zone



7 PRESSURE DROP in catalyst chamber increases with temperature. This is due to increase in both gas velocity and gas viscosity



8 AFTER CONDENSER is installed on slight tilt toward gas exit. Central baffle and tube with closed ends on axis prevent streamline flow. Sleeves around cooling lines lessen danger of burning holes in ¼-in. tubes during welding, keep such holes completely outside condenser for easier repair

of its operation are given in Fig. 2.

Entrainment trap. A $3\frac{1}{2} \times 3\frac{1}{2} \times 17$ in. stainless-steel box filled with about 125 gm of fine stainless-steel wool is located ahead of the blower to stop any entrained liquid carried over from the reflux condenser. The box is tilted so that any trapped liquid will run back into the sphere.

At a gas flow of 100 l/min, the trap has a pressure drop of only 0.25 in. of water after steam has been passed through it for 10 min.

Circulating blower. Design criteria, including restrictions imposed by the reactor stacking, necessitated design and fabrication of a special blower for the system. The original blower using a rotating graphite gas seal and packing has been replaced by the unit in Fig. 3.

Pressure rise in the blower as a function of fan speed was measured with two potential sweep gases, helium and air. Results are shown in Fig. 4.

Catalyst chamber. Laboratory tests indicated that internal catalyst bed heaters were unnecessary, and that pressure-drop data taken with the catalyst bed at room temperature were invalid. The increase in temperature during combination of hydrogen and oxygen causes an increase in gas viscosity and velocity. This results in a serious increase in pressure drop.

To minimize this effect the cross section to gas flow was maximized to improve heat distribution as well as to reduce gas velocity.

The final chamber design if shown in Fig. 5. Catalyst material was alumina pellets, ⅛ in. diameter and ⅛ in. long, coated with platinum (0.3% by weight).

To test the chamber, known rates of hydrogen, oxygen, and sweep gas were passed continuously through individual drying and metering stations, then through the chamber. Exit gas from the chamber was cooled to 10° C, and the total rate of water formation (condensate + humidity) determined. Comparison with the known rate of hydrogen introduction gave the recombination efficiency for a single pass. Recombination efficiency was also determined by hydrogen analysis of gas samples from the chamber inlet and outlet. Good data were not obtained by either method; values ranged from 80 to 103% recombination for a single pass. Time limitations prevented obtaining better data.

Temperature-vs-time plots were continuously recorded by means of thermocouples (Fig. 5). Pressure drop vs time was also recorded. (See Figs. 6, 7.)

After condenser. At 100 l/min, this unit has to reduce gas temperature from about 350° C to at least the sphere temperature at 70° C, and at the same time condense water at the rate of 4 cm³/min of condensate. The very small condenser shown in Fig. 8 is adequate, and a cooling water flow as low as 0.2 gal/min is sufficient to lower exit-air to within 15° C of the inlet water temperature. The double-helix cooling coil is much more efficient than a single helix, presumably because of increased coil area and turbulence.

Liquid trap. Located between the after and reflux condensers, this trap is a 12-in. section of ¾-in. tubing with a valve at the bottom opening into a dump line. The trap holds about 82 cm³ and is normally full of water during operation since this amount collects in the catalyst chamber in about 20 min when reactor power is 25 kw.

Overpressure relief valve. In parallel with the gas bleed valve to the exhaust line is a solenoid valve that opens automatically if the recombiner system exceeds atmospheric pressure. This safety feature eliminates pressure buildup in the system and reduces the possibility of leakage of radioactive gas. The pressure indicator that actuates the solenoid is also connected to one of the reactor safety circuits so that the reactor is shut down if the system exceeds atmospheric pressure.

Typical Operation of System at 25-kw Reactor Power Level

Gas circulation rate	100 l/min
Catalyst chamber drop	2.2 in. H_2O
Reflux condenser drop	4.5 in. H_2O
Maximum system pressure	3.1 in. H_2O
Exhaust line pressure	3.2 in. H_2O
Catalyst bed temperatures:	
Inlet region	467° C
Middle region	438° C
Outlet region	369° C
Reactor solution temperature	75° C
Reflux condenser water:	
Flow	0.17 gal/min
Temperature in	3.5° C
Temperature out	20° C
After condenser water:	
Temperature in	20° C
Temperature out	28° C
Air temperatures:	
Out of reflux condenser	15° C
Into catalyst chamber	45° C
Into after condenser	211° C
Into reactor sphere	33° C

Preliminary Testing

Before installation in the reactor, the system was assembled and tested in mock-up form. Full-size models of the reactor sphere and stack were used, with the sphere filled with a nitric acid solution at the *p*H of the actual boiler solution. A mantle heater kept the nitric acid at 80° C.

Use of hydrogen in the mock-up was unnecessary because of the previous tests on the catalyst chamber. To simulate the recombination process, the chamber was replaced by a combination heater and steam injection unit that had the same pressure drop.

All components operated satisfactorily, but the pressure drop in the system was higher than anticipated, primarily because the pressure drop across the reflux condenser was 25% higher when the coil was wet than when it was dry. At pressure equilibrium, attained in 20–30 min, a blower speed of 4,720 rpm was needed to maintain a flow of 100 l/min.

Installation

Use of a gas disposal system had been considered during conversion from the Hypo to the Supo version of the water boiler; this simplified installation. The reflux condenser replaces a removable level indicator unit, and the catalyst chambers and blower

are placed in shielded boxes that replace concrete shield blocks.

Pressure drops and gas flow rates are transmitted to the control panels from condenser pressure gages designed to resist corrosion and pressure surges. Magnehelic gages (F. W. Dwyer Mfg. Co., Chicago, Ill.) are used to give direct pressure readings at the reactor.

Temperatures at various points in the system are measured with thermocouples and recorded on 0–600° C or 0–100° C Brown recorders.

A drinking-fountain-type water cooler supplies cooling water for the two condensers, which are connected in series. A by-pass valve allows independent adjustment of cooling water for the after condenser.

To keep all gas contamination from the pressure indicators and the gas-sampling valves, an air bleed-in system was installed whereby a few cm^3/min of air can be bled into each of the tubes. It takes about 24 hr for activity to appear at the tube ends with the bleed air shut off, and less than 1 cm^3/min of bleed air is sufficient to keep all radioactivity out.

Performance

During the initial operation reactor power was gradually increased while a close check was kept on catalyst bed temperatures. The first indication of gas recombination appeared at 300 watts, when a slight rise of temperature was observed on the bottom thermocouple, T_3.

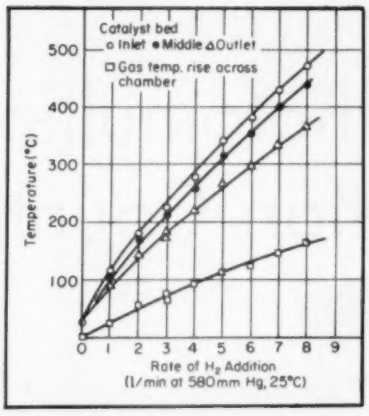
When power was increased to 1 kw, all portions of the catalyst bed rose at a rate of about 1° C/min. Any further change in reactor power appeared on the Brown recorder with only a slight time delay. This quick response at room temperature indicated that the catalyst heater need not be used.

Typical pressure drops and temperatures in the system for a 25-kw reactor power level are tabulated on page 28. At higher power levels, two types of catalyst chamber behavior are observed as the inlet bed approaches 580° C where the hydrogen and oxygen mixture appears to ignite.

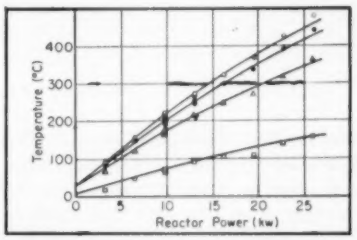
If the reactor is run at powers in excess of 38 kw so that the rate of temperature rise in the catalyst is fairly rapid on approaching 580° C, the inlet bed shows a sharp drop in temperature, whereas the outlet air temperature shows a more rapid rise. The other bed temperatures and that of the catalyst pot itself decrease. These effects are probably due to ignition in the catalyst region.

If the reactor is run at 35–36 kw so that the rate of rise is very gradual when 580° C is reached, a slightly different phenomenon is observed. The inlet bed temperature decreases less rapidly, air outlet temperature decreases, and catalyst pot temperature increases more rapidly. This may be due to burning of the gas in some region preceding the catalyst pellets.

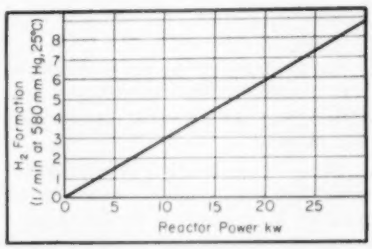
When reactor power is reduced to 25 kw, the catalyst chamber reverts to normal operation.



9 CATALYST CHAMBER temperature vs hydrogen flow rate recorded at equilibrium (after 40 min operation, only slow constant drifts occur, so data taken after this time was considered at equilibrium). Known rates of hydrogen and oxygen (in stoichiometric ratio) were introduced directly above reactor solution with reactor at zero power, recombiner system operating normally



10 CATALYST CHAMBER temperature vs reactor power. Same conditions as in Fig. 9, with reactor power increased stepwise. Flow rate is again 100 l/min



11 RADIOLYTIC HYDROGEN FORMATION as a function of reactor power. Plot was derived from Figs. 9 and 10, using any one of the temperatures as a parameter

Hydrogen Determination

While determination of hydrogen evolution was of immediate interest, actual chemical analysis of gas from the system would have required considerable preparation. Since previous testing had indicated that catalyst chamber temperatures were very dependent on hydrogen concentration for a given rate of sweep-gas flow, the rate of radiolytic hydrogen formation could be correlated with reactor power level (Figs. 9, 10, and 11). Good agreement was obtained using any of the three catalyst bed temperatures, or the sweep-gas temperature rise. The rate of hydrogen evolution was determined as 0.55 mole/kwh. Prior to installation of the recombiner system, the rate of water addition to keep the reactor at constant volume was 0.49 mole/kwh.

As shown in Fig. 10, catalyst-chamber temperatures provide a reasonably good method of measuring reactor power. The inlet bed temperature is the least dependent on the surroundings, but poisoning of the catalyst would move the main reaction zone deeper into the bed and result in lower reference temperatures. Consequently, the most desirable reference is the sweep-gas temperature rise across the chamber at a given air flow.

Conclusions

The recombination system has been operated for 24 months as of March, 1953 (about 80,000 kwh). In this time no detectable change has occurred in the catalyst bed. Neither the external heaters nor stand-by chamber have been needed. With the exception of the original blower seal, the system has worked very satisfactorily.

The only changes contemplated are (1) to increase the recombination chamber capacity to permit higher steady reactor powers, and (2) to add cooling coils to the chamber to permit dissipation of the heat of recombination.

* * *

We would like to acknowledge the assistance of J. W. Starner and J. R. Phillips in assembling and testing some of the equipment.

Five New Photomultipliers for Scintillation Counting

Photomultiplier tubes with new dynode structures and a range of front-end sizes have been designed. Photocathode sensitivities are between 40–80 μa/lumen. Operating and dynamic characteristics of the tubes are described

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IN THE LAST several years, scintillation counters have been used in many new situations, and the demands on the photomultipliers have become more exacting.

In addition to high photosensitivity and high multiplication, it is desirable that the tubes have good photocathode uniformity and low dark current. Of special importance is the collection efficiency of the first dynode in the multiplier structure.

The availability of large crystal phosphors and the varied applications of scintillation counting makes a range of sizes of photomultipliers desirable. Large photocathodes permit the use of large crystals, and this reduces the height of the continuum relative to the peak value of the full energy line in a standard pulse-height analysis. Such a reduction is desirable when dealing with complex spectra.

Small-diameter photomultipliers are of use in prospecting for oil or uranium because they can more easily be dropped into holes drilled in the ground.

Physical Characteristics

Figure 1 shows the range of sizes of the family of photomultiplier tubes developed at these laboratories. The front-end diameters of the multipliers are, starting with the largest, 5 in. (K1198), 3 in. (K1197), 2 in. (6292), 1.5 in. (6291), and 0.75 in. (K1193). Because of the evaporated aluminum layer on the inside of the tubes, the actual cathode diameters will be slightly smaller than the front-end diameters. The photocathodes are a composite surface of cesium and antimony.

The multiplier structure is shown in Figs. 2 and 3. The box dynodes are coated with an activated silver-magnesium alloy.

Electrons from the photocathode enter the first dynode, where their number is multiplied by secondary emission. This process cascades down to the tenth dynode, after which the electrons are collected by a wire-mesh anode between the ninth and tenth dynodes. Each dynode (except the tenth) has a mesh screen attached to it that faces the preceding dynode to enhance secondary electron collection.

The three largest tubes (Fig. 1) have the multiplier structure shown in Figs. 2 and 3. Note that the first dynode is larger than the succeeding ones so that photoelectron collection is enhanced. The shield potential can be independently varied to obtain optimum photoelectron collection.

However, the multiplier structure of the 1½-in. photomultiplier (Fig. 1) has the shield tied electrically to the first dynode, and the first nine dynodes are of the same size. By scaling this latter structure down to half size, the structure for the ¾-in. photomultiplier was obtained. Although the ¾-in. multiplier shown here has a curved photocathode surface, these cells are also constructed with flat photocathode surfaces.

All the photomultipliers shown in Fig. 1 have ten dynodes, but multipliers have been built at these laboratories with as few as five and as many as twelve dynodes. This type of structure has the advantage that the number of stages and the distribution of voltage between dynodes can be varied at will without redesigning for focusing between dynode stages.

Operating Characteristics

The photocathode sensitivities fall in the range of 40 to 80 μa/lumen, measured with a tungsten lamp at a color temperature of 2,870° K. The multiplication falls in the range of 1.0

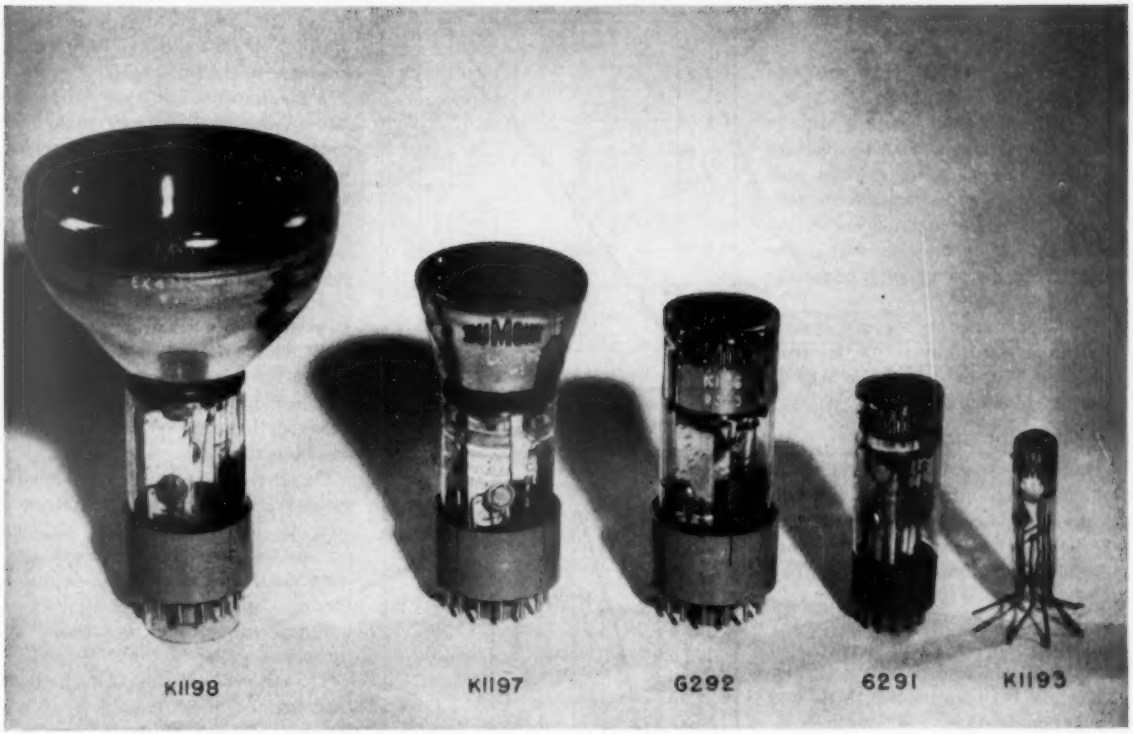


FIG. 1. Photomultiplier tubes with front-end diameters of 5, 3, 2, 1.5, and 0.75 in.

to 5.0×10^5 for 105 volts/stage, and 0.7 to 16×10^6 for 145 volts/stage.

For steady-state illumination, the flow of current in the photocathode to replace the photoelectrons causes a radial potential drop in the cathode. It is thus possible that the first dynode potential may not be high enough to draw away all photoelectrons under such circumstances. Figure 4 shows how the photocurrent from a cathode on a TC (transparent conductive) coating varies linearly with light intensity for steady-state illumination; saturation is reached for a cathode without TC coating. For pulse analysis, however, such as in scintillation counting where the light pulses are in general of very low intensity, the TC coating is not necessary. Further characteristic curves are shown in Figs. 5, 6, and 7.

Silver-magnesium dynodes will, in general, show more stable operation at high average current than will Cs-Sb or Cs-Ag-O secondary-emission surfaces. For this reason it has been possible to specify the maximum average anode current as 5 ma while peak anode current is 25 ma.*

* The ratings for the 0.75-in. diameter photo-multiplier will be somewhat lower.

With this type of box-dynode multiplier structure, where high-voltage dynodes are relatively far from low-voltage dynodes, one can approach relatively high voltage per stage before noise due to leakage currents becomes objectionable. In general,* the maximum voltage that can safely be applied

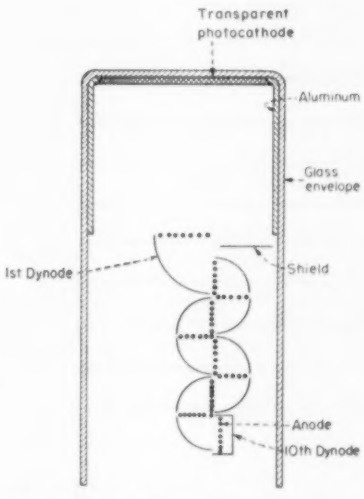


FIG. 2. Cross section of the tube that is shown in Fig. 3

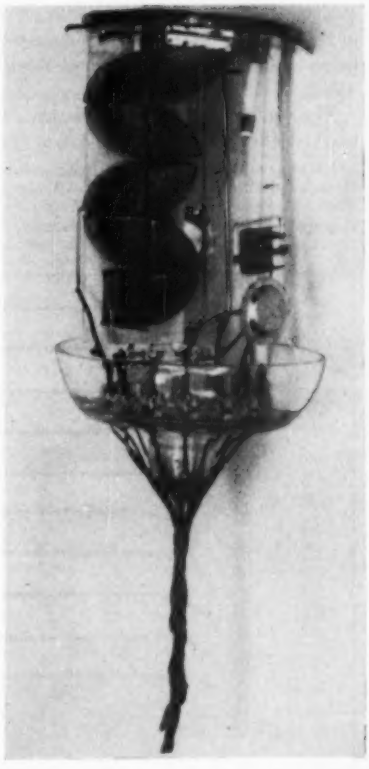


FIG. 3. Structure of the three largest multiplier tubes

to the photomultiplier is 175–180 volts/stage.

The voltage between photocathode and first dynode on the 2-in., 1½-in., and ¾-in. photomultipliers is usually set somewhat higher than the voltage per stage. For the 3-in. and 5-in. cells this voltage can be run considerably higher because the cathode connection is brought out on the cone part of the tube (this connection cannot be seen in Fig. 1).

The capacitance of a given dynode to all other electrodes is, on the average, 4 $\mu\mu$f whereas that of anode to all other stages is 3.3 $\mu\mu$f.

Dynamic Characteristics

Figure 8 shows the effect of shield voltage on resolution and pulse height for the 6292 tube (an NaI(Tl) phosphor was used for the measurements). Note that the curve is quite different for two tubes of the same type.

Other workers in the field have found that there is, in general, an optimum shield voltage that is usually somewhere between photocathode and first-dynode voltage. Where this optimum lies may well depend on mechanical positioning of the multiplier structure. In general, where every bit of resolution is required, it is advisable to run a curve of resolution vs shield voltage.

The shield potential also has a marked effect† on the resolution of the larger-area photomultipliers. The optimum potential in this case usually lies close to the photocathode.

Measurements on the large-area photomultipliers indicate that these tubes have a resolution that compares well with the smaller 6292 and 6291 tubes.

There is some variation in cathode sensitivity over the large-area photocathodes. In general, the ratio of minimum to maximum sensitivity as measured by a small crystal with a Cs^{137} source has been about 0.75 to 0.80. These measurements were made on developmental tubes, and it is believed that this cathode uniformity can be much improved.

On the other hand, the smaller cathode areas are extremely uniform as seen on a flying-spot scanner (although no quantitative measurements have been made on these). This is due to the fact that a smaller area allows more uniform evaporation in forming the cathode.

The effect of voltage between photocathode and first dynode is also of interest. This is illustrated in Fig. 9. All tubes tested showed similar dependence. There is a definite trend toward improved resolution with higher voltage between first dynode and photocathode. This is due to two effects: (1) better collection efficiency and (2) higher multiplication on the first dynode. The second effect is probably the important one.

The collector electrode (anode) is a mesh between the ninth and tenth

† We are indebted to the Instruments Branch of the Health and Safety Division of N. Y. Operations Office, U. S. Atomic Energy Commission, for this information.

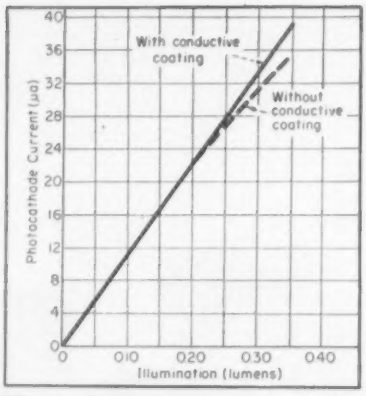


FIG. 4. Photocathode current vs illumination

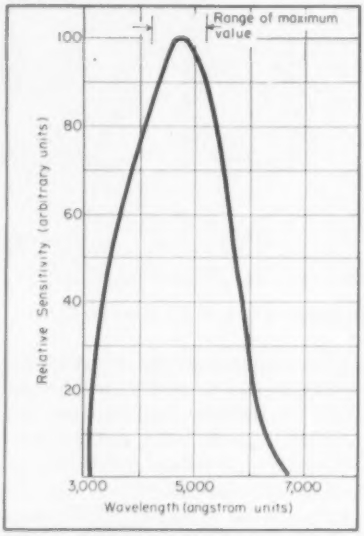


FIG. 5. Spectral sensitivity (S9 response) for equal illumination at all wavelengths

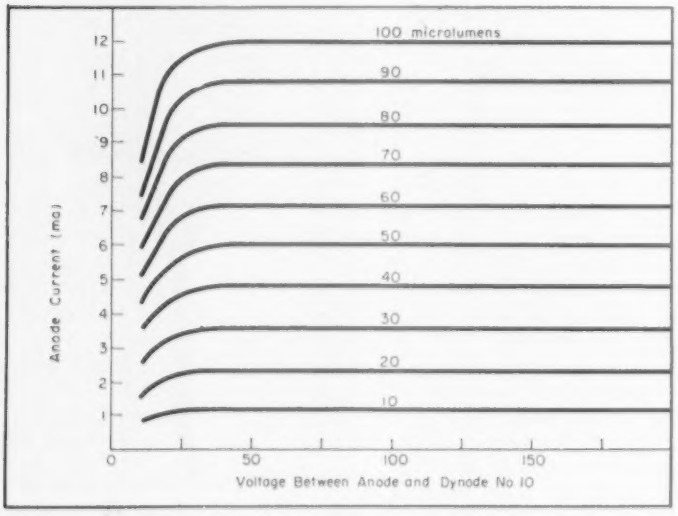


FIG. 6. Average anode characteristics at 145 volts/stage

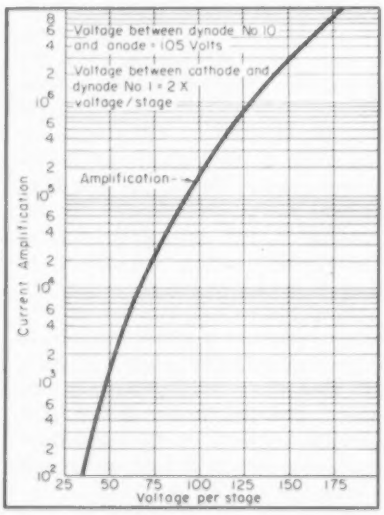
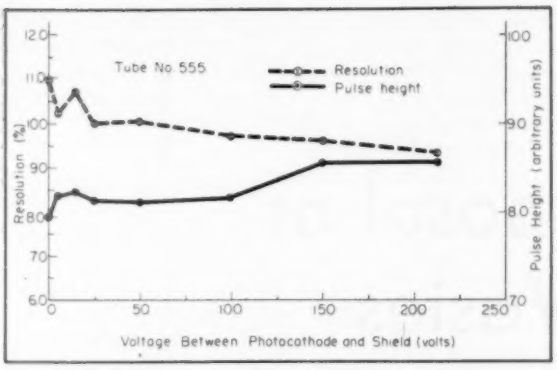


FIG. 7. Multiplier gain vs voltage per stage



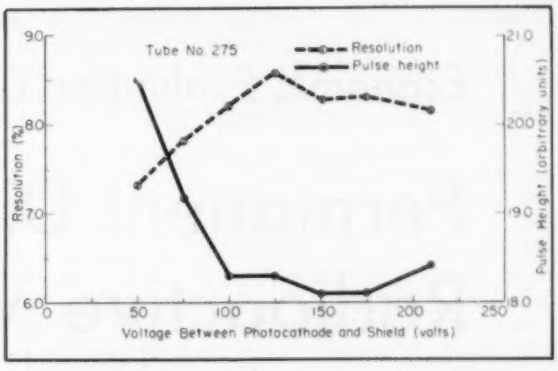


FIG. 8. Variation of pulse height and resolution with voltage between shield and photocathode for type 6292 tube (Cs-137 source). Potential between first dynode and photocathode is 212 volts

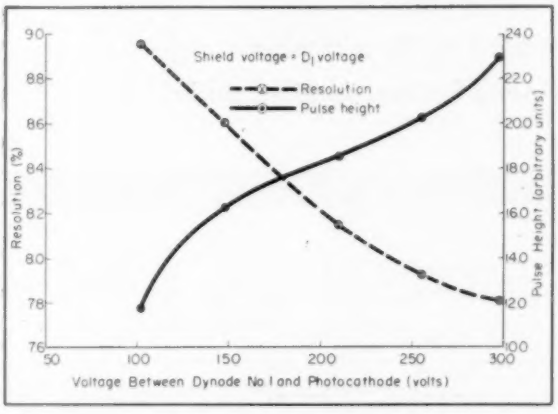


FIG. 9. Variation of pulse height and resolution with voltage between first dynode and photocathode for type 6292

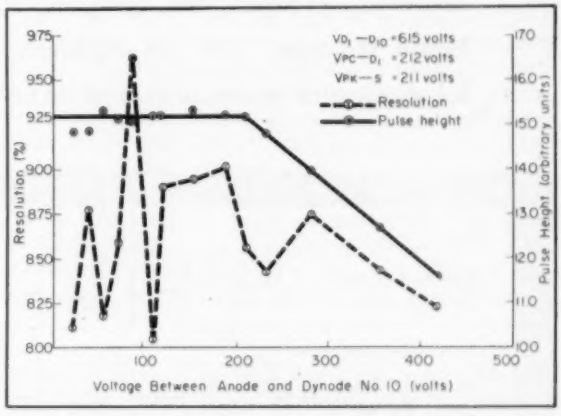

VD1 — D10 = 615 volts
VPC — D1 = 212 volts
VPK — S = 211 volts
Resolution
Pulse height
Resolution (%)
Pulse Height (arbitrary units)
Voltage Between Anode and Dynode No. 10 (volts)

FIG. 10. Variation of pulse height and resolution with voltage between anode and tenth dynode for type 6292

dynodes. At high enough voltages, this mesh can collect electrons directly from dynode 9 rather than from dynode 10 alone. Figure 10 shows that this occurs at voltages between anode and dynode 10 exceeding 200 volts, and when the voltage between dynodes 9 and 10 is 61.5 volts.

The improvement of resolution with increasing voltage between anode and dynode 10 is puzzling. At present it is uncertain whether this is a definite characteristic of the tube. This point is being investigated further.

While work is still being continued on the 3-in. and 5-in. photomultipliers, larger sizes are also in development. Much work is still necessary on these latter tubes, however, especially in regard to cathode uniformity.

* * *

The photomultipliers developed by these laboratories are the result of the combined efforts of many people. Particular acknowledgment in this regard is due to Philip Snell, the project engineer on this work, and Arthur Williams, who constructed the multiplier sections during the developmental work. Valuable assistance in performing measurements was rendered by R. C. Palmer and R. W. Deichert. Many of the measurements referred to were performed on equipment belonging to the Instruments Branch of the Health and Safety Division, N. Y. O. O., AEC. The author is also indebted to H. D. LeVine and R. T. Graveson for many stimulating discussions during the development of these photomultipliers. Finally, the author wishes to express appreciation to S. J. Koch and R. E. Rutherford, Sr., who directed the work, for their continued encouragement and valuable suggestions.

Much of this article is based on work performed under AEC Contract AT(30-1)-1336.

More about Al Pitting in Reactors

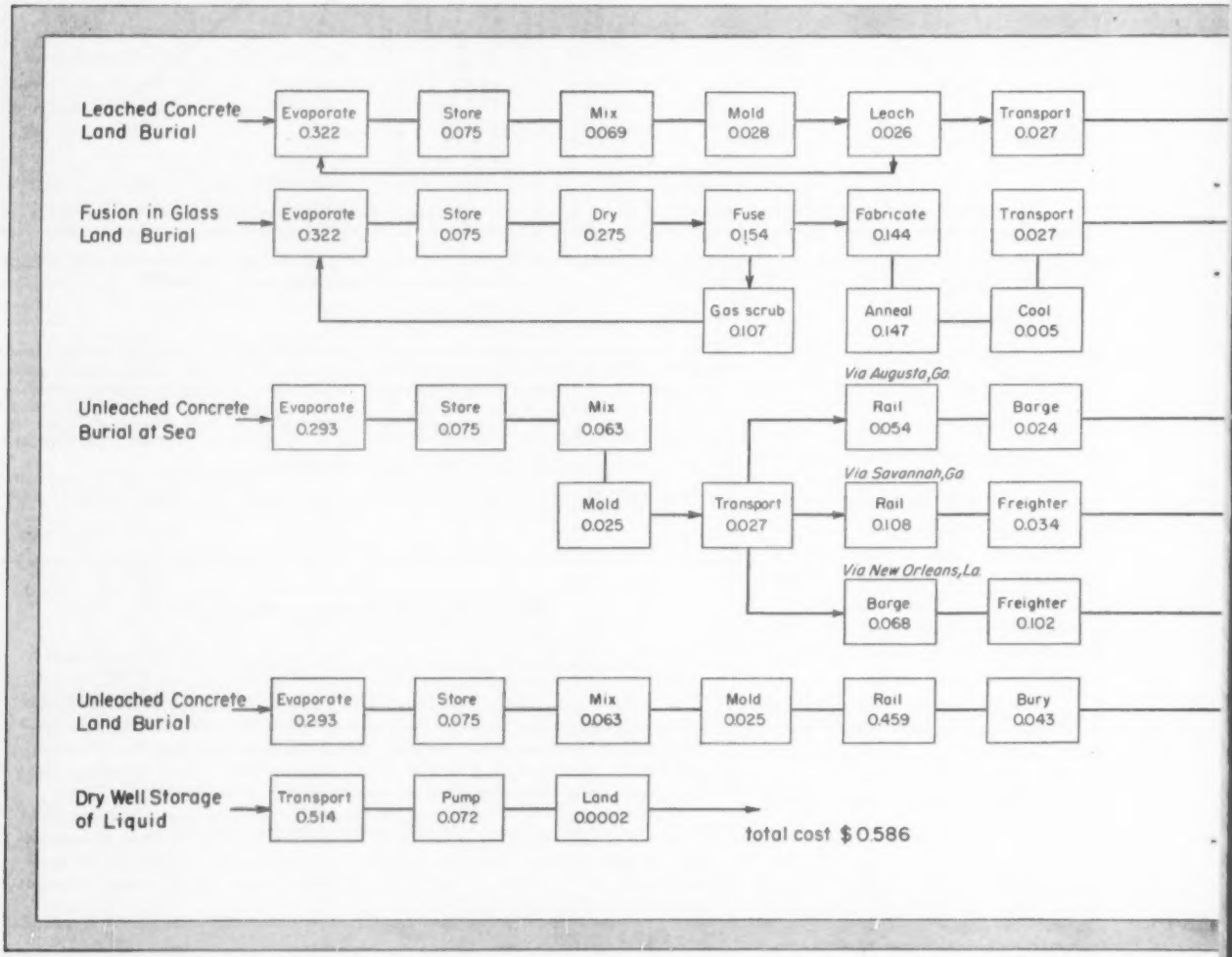
Corrosion of the aluminum-jacketed fuel rods in the heavy-water reactor at Kjeller, Norway has been reported previously (NU, July '52, p. 19). Inspection a year later (December, 1952) has shown that chiseling off the small pittings at the time of the first inspection was very effective in preventing further corrosion. No new pitting was observed, but the aluminum was clearly more oxidized than at the first inspection. More corrosion was observed in the central part of the reactor than at the periphery.

For inspection, the highly radioactive fuel elements were hoisted into a cylinder of lead rings equipped with apparatus for projecting a picture of the surface onto a viewing screen. Apparatus and results have been described by J. Brun of the Joint Establishment for Nuclear Energy Research in JENER-14.

Economic Evaluation of

Permanent Disposal of Radioactive Wastes

Cost analysis indicates that known methods of permanent disposal definitely can compete with semipermanent liquid storage. But the optimum method varies with plant location, and techniques and hazards need further, detailed study



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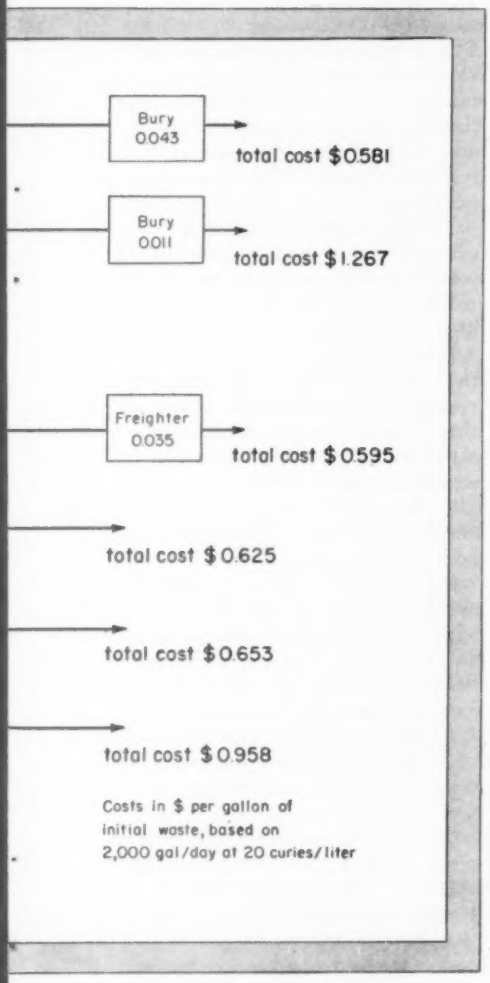
R. G. SHAVER, and
C. W. SORENSON
Engineering Practice School
Massachusetts Institute of Technology
Oak Ridge, Tennessee

THE CURRENT SOLUTION to the problem of disposing of large quantities of radioactive waste is to evaporate the dilute waste solutions to saturation and store the resulting liquid concentrate in underground steel tanks. Such storage is expensive; Manowitz *et al.* (*1*) have given a cost of $0.44 per initial gallon of waste for evaporation and storage at Oak Ridge National Laboratory. Cost is increased when cooling coils are required in storage tanks to remove heat generated by radioactive decay in large quantities of high-level waste during storage.

In addition, such storage is not permanent. Corrosion makes eventual replacement of the tanks necessary. Some hazard exists, for leakage could readily contaminate ground water and surroundings.

These factors indicate the desirability of developing a storage method that will be relatively inexpensive, but permanent and radiologically safe. Various proposals for concentration and storage have been made; most of them involve solidification of wastes and storage of the resultant solids. While some cost data are available for these proposed methods, they are based on a variety of concentrations and waste activities.

The purpose of the study reported here was to make an economic comparison of the proposed methods and to estimate the economic feasibility of those methods showing industrial promise. A lack of operating data and, in some cases, costs of units used in processes made this study necessarily qualitative. Economic comparison of the processes is possible, however, and the results do indicate which processes are of most interest and where further experimental work is necessary.



◀COMPARATIVE COSTS in dollars per initial gallon of waste for five proposed methods of disposing of fission-product waste. Based on waste flow of 2,000 gal/day at an activity of 20 curies/liter

Basis of Study

To obtain a workable basis for economic comparison, processes were evaluated and costs estimated for a plant at Oak Ridge, Tenn., with an assumed production rate of raw waste of 2,000 gal/day at an activity of 20 curies/liter. Thus variations of disposal costs with plant location, production rate, and activity are eliminated.

Certain assumptions based on current waste disposal practice have also been made:

1. Any effluent stream from the process under consideration that is not sufficiently low in activity to be safely discharged to the surroundings must be stored or decontaminated.

2. Any permanent storage facility must be sufficiently shielded to protect personnel from direct radiation. In the case of underground storage, there must be no chance of leaching of radioactive materials by ground water, nor should there by any possibility of concentration of radioactive materials by plant or animal life.

3. Generation of heat by radioactive decay should be low enough in permanently stored material that radioactive components do not volatize.

4. In the case of temporary storage of high-level wastes to reduce activity through decay before permanent disposal, it has been assumed that the optimum temporary storage is about 5 years. Activity decays to less than 2% of the initial value in this period (*2*), but the decrease in activity with time thereafter is insufficient to justify the cost of storage.

Scope of Study

In the light of these assumptions, nine proposed methods of concentration and disposal of wastes have been evaluated qualitatively. Five showing industrial promise for high-level wastes have been compared on a cost basis. The results of this comparison are shown in the illustration on page 34. Each disposal method has been broken down into a series of operations such as evaporation, storage, drying, etc. The cost of each step and the total cost are given for each method.*

In the following paragraphs, each of the promising proposals is outlined and its cost discussed. The four proposals that were not subjected to cost analysis are discussed in the section "Less Promising Methods."

Dry Oil Wells

Pumping of high-level radioactive wastes into exhausted or "dry" oil wells has been proposed (*3*). Such wells, existing from 1,000 to 10,000 ft below the surface of the ground, would be gas tight, and migration of the waste solutions through the rock strata would be slow enough that no danger of radioactive contamination would be present (*4*).

This disposal method offers the advantage that the wastes need not be processed but may be disposed of directly. The major requirement is that dry wells be available within a reasonable distance of the waste source. These dry wells must be of reasonable capacity, and there must be

* A detailed analysis of costs is given in the appendix of K-1005 (1953). Operating experience at Oak Ridge National Laboratory, and cost data from studies of the proposed methods was used wherever possible.

an adequate method of transporting high-level wastes to the dry wells without radiation hazard.

The cost of this disposal method was estimated for use with a dry well 100 miles from the site of waste production. The major portion of this cost is incurred in transportation of the wastes. A truck carrying 150 gal of waste would require 10 tons of lead shielding; its cost is estimated at $20,000. Under the assumed conditions, seven such trucks would be required, and, in addition to their depreciation, labor and overhead would also add to transportation cost.

Rail transportation might be used, but at longer distances cost would be prohibitive.

High transportation costs limit use of this method to installations with dry wells nearby, within 100 miles. It is doubtful if such a fortuitous location of an AEC installation has occurred, but use of dry wells for disposal might well be a factor to consider in plans for location of new plants producing radioactive wastes.

Fusing in Glass

Fusion of wastes into a glass that could be buried at a local site has been suggested (*5*). This process would involve evaporation of the liquid wastes to dryness, fusion of these solids with an inexpensive glass, and manipulation of the product into a form suitable for burial. It would be necessary to recover radioactive materials that volatize during fusion.

The main advantages of this method are that the resulting glass should not be subject to leaching, and that it should be possible to permit fairly high temperatures in the final buried product.

The costs involved have been estimated on the assumption that 1 gal of raw waste will be fused with 0.26 lb of glass after decay storage and evaporation to dryness. No preleaching step has been included in the process. The final product would be similar to marbles since larger masses would involve annealing problems.

The costs for evaporation and drying include a 10% increase to cover recycling of scrub water needed to recover volatile radioactive products from the glass furnace off-gases.

No fusions of dry radioactive material in glass have been made to date, and in view of the cost estimate given here it is questionable whether an experimental program is justified. Certainly little consideration should be given to fusion of wastes in glass unless other proposed methods prove entirely unsuitable.

Concrete

Incorporation of concentrated liquid wastes into a concrete monolith that can be buried for permanent disposal has been proposed (*6, 7*). The principal difficulty is leaching after burial. Experiments with radioactive materials incorporated in Portland-cement concrete indicate that about 5% of the radioactivity is leached out fairly rapidly, but that thereafter substantially no more radioactivity is removed (*6, 7*). These data are extremely meager, however, and more experimental work is required for accurate evaluation of leaching. The effects of soil chemicals on radioactive concrete should also be studied.

Based on the studies to date, three proposals have been made for safe, permanent disposal: sea or land burial of unleached concrete, or land burial of leached concrete.

Land burial, unleached concrete. If concrete is to be buried on land without preleaching, the burial site must have a sufficiently low rainfall to preclude the possibility of ground-water contamination. The most promising area, Death Valley, was considered in making cost estimates.

It was assumed that the raw liquid waste would be concentrated by a factor of 10, and that the concentrate would then be used in place of water in making concrete; 1 gal of raw waste thus would make 5.8 lb of concrete. It was also assumed that preliminary storage of the waste solutions for 5 years would be adequate to reduce the radiological hazard in transporting the concrete product and to keep the concrete thermally cool enough for safe handling. The bulk shipment rate for rail transportation to Death Valley was increased by 200% to allow for lead shielding and handling precautions.

Compared to other disposal methods, transportation costs are high. In choosing a disposal method, one must balance this cost of transportation against the added cost incurred if preleaching is used, especially for installations near areas of low rainfall.

Sea burial, unleached concrete. Evans has suggested making a nonradioactive concrete "projectile" with a tank fastened on the rear to contain concentrated liquid waste (*2*). This projectile was to be dumped 500 miles off the coast of Georgia, where the ocean is 15,000 ft deep with a muck bottom of 100–200 ft and stagnant water above the bottom. The projectile was designed to reach a high velocity during descent so that it would bury itself deeply in the muck, eliminating radiological hazard.

If the projectile were made of radioactive concrete, construction of a corrosion-proof pressure-adjusting tank could be eliminated. This modification of the original proposal has been used as the basis of cost studies.

The cost of preparing such projectiles should be the same as that for preparation of slabs for land burial. Differences in costs for the two burial methods arise in transportation. Three routes for transporting the concrete projectiles to the proposed burial site have been considered: (1) by barge through the TVA system to the Mississippi River and to New Orleans, then by ship to the site; (2) by rail to Savannah, Ga., then by ship; (3) by rail to Augusta, Ga., then by ship. Barge costs were tripled to allow for shielding and special handling.

For plants located on water navigable to ocean-going vessels, it is reasonable to state that disposal at sea will be cheaper than leaching the concrete and burying it on land.

Land burial, leached concrete. On the basis of leaching experiments previously discussed, it has been assumed that it is possible to preleach radioactive concrete sufficiently so that no significant leaching will take place after burial. Further assumptions include: (1) a 10% additional load imposed on evaporators and cement-mixing facilities by the preleaching process; (2) storage and burial costs same as without preleaching; (3) available and readily accessible locations for burial nearby or on the site; (4) 6 ft of earth sufficient to eliminate hazard from direct radiation; (5) no evolution of volatile radioactive substances at temperatures below the decomposition temperature of concrete.

The economic advantage of this proposal depends on minimizing transportation costs by nearby burial. If the preceding assumptions are verified, this method appears attractive. Its cost is the lowest of the five methods

investigated, comparing favorably with the cost of semipermanent storage.

An alternative method allowing local burial is encasement of radioactive waste in metal barrels (*6*). However, analysis of costs indicates that this would be approximately 2–10 times as expensive as preleaching.

Less Promising Methods

Four processes studied were not considered usable for high-level wastes, and no cost analysis was made. However, these processes may be usable for lower concentrations and activities that require decontamination factors (ratio of feed to outlet activity) lower than the 10^6 required for discharge of high-level effluents to the surroundings (*8, 9*).

Ceramics.* Use of montmorillonite and kaolinite clays as adsorbents for radiochemical wastes has been proposed by several authors (*6, 11, 12*). Fusing of such clays into ceramics for disposal has been suggested at Argonne National Laboratory (*6*).

Experiments indicate that the clays are good adsorbents for metal wastes in low concentration (*12*), but the decontamination factor was only about 30. Furthermore, little work has been done on the firing of these adsorbent clays into disposable ceramics.

Sulfur fusion. One proposal involves evaporation of liquid wastes to dryness, and fusion of the resulting solids with molten sulfur to form a disposable solid product upon cooling. Leaching by ground water after burial might be surmounted, but because of the low melting point of sulfur (112° C), the authors feel that heat generated during decay (*13*) would be sufficient to melt the buried product. This method would therefore be entirely unsuitable for permanent disposal.

Coprecipitation. Precipitates provide no advantage over concentrated solutions since both have to be bound into solids before final disposal. Coprecipitation of radioactive wastes with aluminum hydroxide, clays, and similar flocculent precipitates is not considered feasible for production of a solid product on an industrial scale. Decontamination factors are 1,000 or lower (*14*), and the voluminous precipitates are difficult to filter.

Electrolytic deposition. A system of producing a solid product by electrolytic deposition has been proposed (*15*), but no experimental data are available. It is felt that this method would give insufficient decontamination since, if the electrolysis were carried out in aqueous solution, the chemical reactivity of some of the fission products (such as Ba^{137}) is too great to permit effective decontamination of the solution. Electrolysis from a melt would involve extreme volatilization problems with a resultant radiological hazard.

* * *

The authors would like to express their gratitude and appreciation to the following persons whose cooperation has made this work possible: to W. K. Eister and C. D. Watson for their helpful comments; to E. J. Wilkowski for information about the ORNL tank farm; to J. Byrne, director of the Oak Ridge Practice School; and to numerous persons at ORNL who contributed information. This article is based on AEC report K-1005, and is prepared from work performed at Oak Ridge National Laboratory, operated by Union Carbide and Carbon Corp. for the Atomic Energy Commission.

Conclusions and Recommendations

The end results of this economic study of methods of disposing of high-level wastes can be summarized as follows:

1. The cost of permanent disposal for any AEC installation should lie in the range of $0.50 to $1.00 per initial gallon of waste. Such figures are definitely competitive with the present $0.44/gal for semipermanent liquid storage.

2. The optimum method of disposal for a given installation will be dependent primarily on the location of the plant with respect to dry wells, water transportation, and areas suitable for the direct burial of unleached concrete.

3. Further detailed economic evaluation should be undertaken at Oak Ridge National Laboratory to determine whether it would be more advisable to leach concrete and bury it on the area or to provide transportation for burial of concrete at sea.

4. Experimental work is justified in developing methods of mixing, pouring, and handling of radioactive concrete.

5. Further work should be done on the preparation of nonleachable concretes. More work is necessary concerning the leaching of concrete by waters in the ground.

6. A detailed survey of the radiological hazards involved in any plan of disposal should be considered necessary before any action is taken.

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*For a different view of this work, see "Letters," p. 82.

Stray Radiation Levels in the Vicinity of Betatrons

Betatrons of 100, 50, and 15 Mev were surveyed to determine the γ-ray and neutron levels in the surrounding areas. Much of the radiation hazard arises from secondary targets, such as the accelerator "donut" or objects in the beam path

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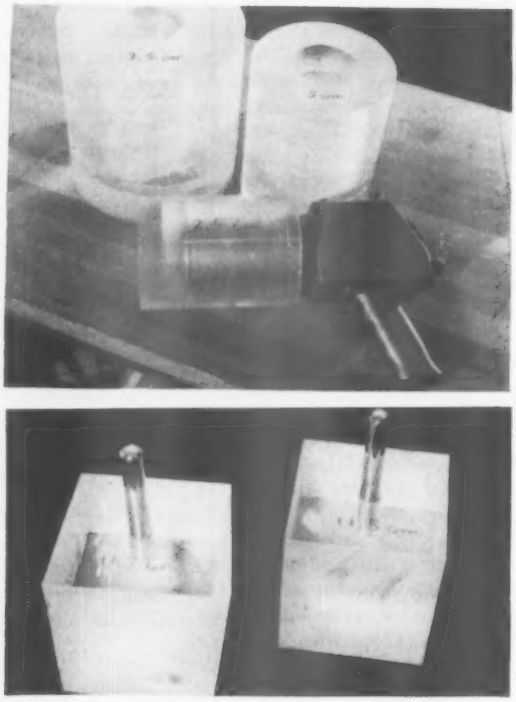

FIG. 1. Lucite absorbers for r-thimbles (top) and Cutie Pie-type survey (bottom)

SOME SIXTY BETATRONS and synchrotrons (*1–4*) are under construction or in operation in the United States and Canada. These machines are not so numerous that they pose a wide-scale problem for the industrial hygienist. However, the growth trend shows a steadily increasing number used in industrial and medical applications.

The nature of the radiation encountered in proximity to betatrons and synchrotrons may vary from one machine to another. For the survey reported here, G. E. betatrons were surveyed for γ-rays and fast and slow neutrons.

Stray Gamma Radiation

Figure 2 illustrates the distribution of stray gamma radiation that might be found in proximity to any high-energy betatron or synchrotron similarly shielded. In this case, a 100-Mev betatron was operated at 1,425 r/min at 1 meter from target and at 100 Mev. All readings were obtained with an ionization-type survey instrument or with r-thimbles, shown in Fig. 1. Personnel are not usually allowed in any of the shaded areas.

Of particular interest is the "stray beam" of radiation that undoubtedly originates, not from the main target, but from some such secondary target as the wall of the "donut" in which the electrons rotate. Frequently these beams may be of very small angle and high intensity. Therefore, the response time of the instrument used for a survey should be known so that such beams are not overlooked by too rapid transversing.

Industrial betatron. Figure 3 is a plot of a γ-ray survey of a G. E. industrial betatron (*5*). The beam axis is at 0 deg, and 180 deg is immediately behind the machine. All readings, except as designated, were in the plane of the electron orbit and were taken with ⅛-in. lead caps on the ionization chambers.

The readings of a few roentgens per hour that were found immediately behind the machine were due to backscatter from the target and to stray electrons that strike the wall of the donut as they are accelerated.

Neutron Flux

A survey of fast- and slow-neutron-flux distribution (Fig. 4) was made of the 100-Mev betatron used, together with a neutron velocity spectrometer, as a pulsed neutron source (*6*). The survey was made before all water and borax neutron shielding had been posi-

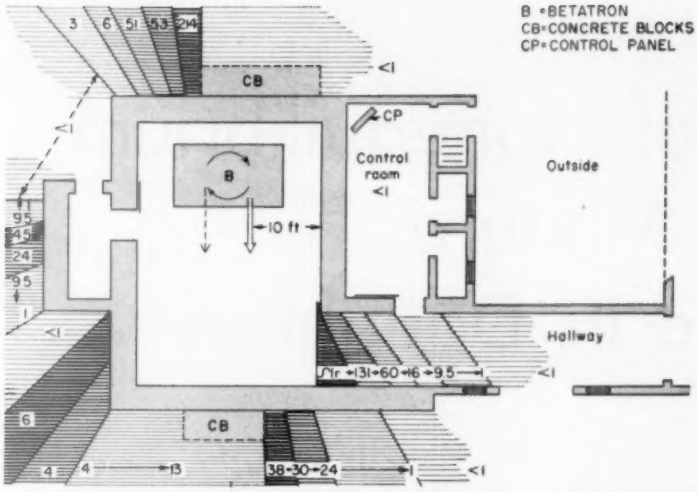

FIG. 2. Stray gamma radiation levels (in mr/hr) in vicinity of 100-Mev betatron. Readings outside of building made at 3 ft from outer wall

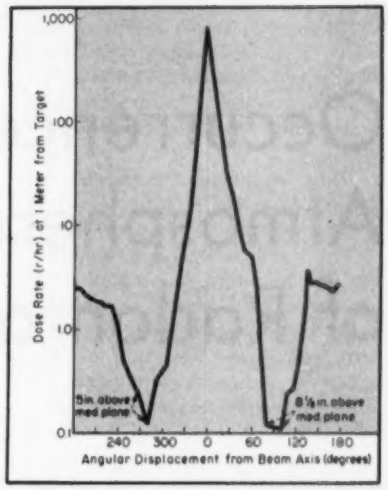
Dose Rate (r/hr) at 1 Meter from Target
Angular Displacement from Beam Axis (degrees)
8 in. above med plane
8½ in. above med plane

FIG. 3. Survey of 15-Mev industrial betatron

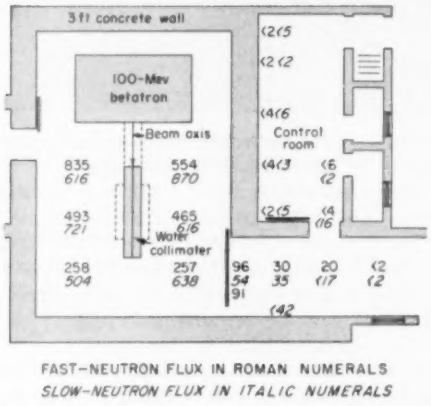

FIG. 4. Flux distribution (n/cm²/sec) with 100-Mev betatron as pulsed neutron source

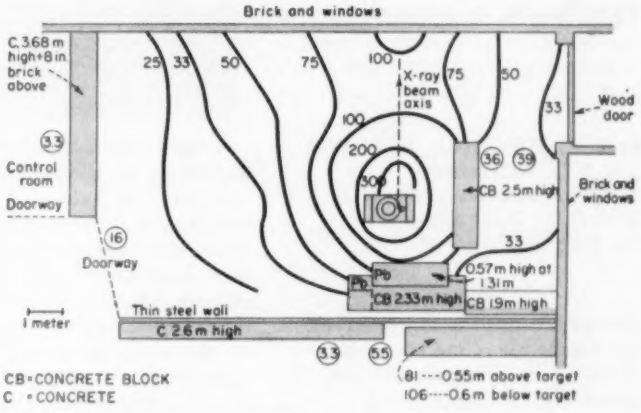

FIG. 5. Slow-neutron survey of 50-Mev betatron (isodose curves in neutrons/cm²/sec)

tioned. The betatron was operated at 50 Mev.

For the survey of slow-neutron regions, we found rhodium foils quite adequate. Two foils were used each time; one in a standard position was used as a monitor so that the readings of the other, the detector foil, could be corrected for variations in betatron output (7).

The equipment for measuring activity induced in the foils consisted of two scalers synchronized through an interval timer with the betatron. When the neutron beam ceased, the timer started, allowing 44 sec—one rhodium half-life—for collection of the Rh foils. At the end of this interval, both scalers commenced counting and continued through 3 half-lives.

The only area outside the betatron room that was above the maximum permissible flux of 25 neutrons/cm²/sec was immediately adjacent to the steel door in the hallway (8). This area is unoccupied during betatron operation.

Slow-neutron survey. Figure 5 shows the results of a slow-neutron survey of a 50-Mev betatron (9). This survey was made using the same equipment and similar technique as those described for the neutron survey of the 100-Mev betatron, although the 50-Mev survey preceded the 100-Mev.

The area where the isodose curves appear was not accessible to personnel, and no appreciable flux rates were found outside this area. It is interesting to note the 100-neutron/cm²/sec isodose curve that appears near the wall around the beam axis. This indicates the importance of materials placed in the primary beam as secondary-neutron and γ-ray sources.

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Occurrence of Nonequilibrium Atmospheric Mixtures of Radon and Its Daughters

Analysis of radon-daughter decay curves permits determination of the atmospheric concentrations of the daughters. With this data, the effectiveness of ventilation in protecting uranium-mine workers can be more accurately evaluated

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INHALATION OF RADIOACTIVE MATERIAL constitutes one of the most important health hazards associated with the uranium mining industry (*1*).

Several methods for estimating the health hazards connected with specific concentrations of radon and its daughters in an atmosphere have been developed (*2, 3*). However, to date, a satisfactory means of measuring these concentrations has not been available. The usual approach has been the assumption of radioactive equilibrium between radon and its daughters (*2*).

Since radon is a gas, it is to be expected that, of a given amount inhaled, a substantial fraction is expelled in breathing before it can decay. On the other hand, the daughters RaA, RaB, and RaC are not gaseous, and their half-lives are measured in minutes. Thus, a relatively large fraction of the inhaled daughters may be expected to decay in the lungs. In general, the hazard resulting from the inhalation of radon itself is practically negligible as compared to the total hazard resulting from inhalation of radon in radioactive equilibrium with its daughters.

It has been suspected that, due to the effects of natural and artificial ventilation in uranium mines, the daughters of radon may occur in concentrations reflecting something less than equilibrium with radon. For example, Morgan (*3*) estimates that the radiation dose to the lungs based on the alpha emissions from radon alone constitutes only about 0.3% of the total dose resulting from the inhalation of the same amount of radon taken together with its daughters. This calculation was based on the assumption of equilibrium for Rn and RaA and 50% of equilibrium for RaB and RaC.

Table 1, based upon Morgan's formula, indicates the health hazards resulting from inhalation of various nonequilibrium mixtures of radon and its daughters.

Under natural conditions of little or no ventilation, the relative concentrations of the daughters are probably at or near the equilibrium condition, and the hazard is almost the total possible hazard. However, artificial ventilation may have a marked effect on the equilibrium ratios as well as on the actual concentrations of radon. If this is the case, the actual hazard in a ventilated mine is considerably less than the hazard estimated on the basis of observed reductions in the concentrations of radon only.

The method of determining relative concentrations of the daughters of radon in a mine atmosphere consists of mathematical analysis of the observed alpha-decay curve from a filter paper sample of the atmosphere. The shapes of such decay curves are significantly affected during the first 45 min after sampling by the actual equilibrium ratios, becoming quite similar after about 1 hr of decay (see Fig. 1). Accordingly, analysis of the decay curves is based upon the first 45 min of decay.

Since the gaseous radon cannot be retained on a filter paper, this method of analysis yields only information regarding the concentrations of RaA, RaB, and RaC, with RaA as parent. However, taken together with other information obtained as to radon concentrations, it also provides a logical means for estimating the relative concentrations considering radon as the parent.

Theory

Two mathematical developments are necessary as basic theory for analysis of the observed decay curves. First, a theoretical expression for the build-up of activity on the filter paper during sampling must be developed, and, secondly, an expression is required for decay after sample collection is stopped.

Specific atmosphere concentrations

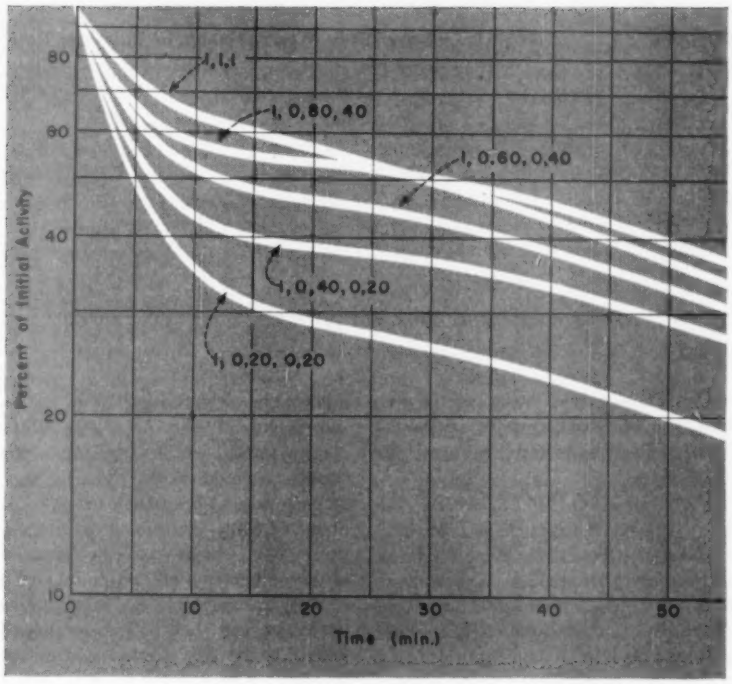

FIG. 1. Theoretical decay curves with RaA as parent (ratio 1, 0.60, 0.40 indicates that RaB and RaC are present at 60% and 40% of their possible equilibrium concentrations)

TABLE 1—Inhalation Hazard of Nonequilibrium Radon-Daughter Mixtures

*Equilibrium ratios**	*Dose† (rem/week)*	*Percent of equilibrium dose*
1, 1, 1, 1	13.7	100.0
1, 1, 0.90, 0.80	12.0	87.5
1, 0.90, 0.80, 0.70	10.6	77.4
1, 0.85, 0.65, 0.45	8.2	59.8
1, 0.75, 0.50, 0.30	6.2	45.3
1, 0.75, 0.40, 0.15	4.7	34.3
1, 0.50, 0.25, 0.10	3.0	21.9
1, 0.35, 0.15, 0.05	1.84	13.4
1, 0.25, 0.10, 0.05	1.32	9.6
1, 0.15, 0.08, 0.03	0.94	6.9
1, 0.10, 0.05, 0.00	0.50	3.7

* Relative concentrations are given as decimal fractions of possible equilibrium concentrations based on radon as parent.

† Based on an atmospheric concentration of 100 $\mu\mu$c/liter of radon.

of the daughters result in a particular set of initial numbers of the daughters for decay, once sampling is stopped. These initial numbers of the daughter elements can be determined by analysis of the observed decay curve, and then converted back into the atmospheric concentrations during sampling. An outline of the required theory follows, omitting the lesser details.*

Table 2 includes the relevant nuclear data for radon and its daughters. In the case of RaB and RaC, approximately 99.96% of particles decay by the emission noted.

The following nomenclature is used:

Q_i = atmospheric concentration in atoms/liter of the ith isotope (i = 1,2,3 . . . . .)

t = duration of sampling (minutes)

$N_i(t)$ = number of atoms of the ith isotope on the filter paper after t minutes of sampling

N_i^0 = number of atoms of the ith isotope at completion of sampling—hence, the initial number for decay. $N_i^0 = N_i(t')$, if t' = sampling period

T = decay time (minutes); $T = 0$ at completion of sampling period

$N_i(T)$ = number of atoms of the ith isotope remaining after decay time T

Q_i^∞ = atmospheric concentration of the ith isotope at equilibrium

v = sampling rate (liters/minute)

Build-up during sampling. The build-up during sampling may be developed by considering the deposition, decay, and formation from the parent for each isotope. The general equation

$$dN_i(t)/dt = Q_i v + \lambda_{i-1}N_{i-1}(t) - \lambda_i N_i(t) \quad (1)$$

may be integrated to evaluate $N_i(t)$.

For $t = 5$ min, $N_i(t)$ becomes

$$N_2^0 = 2.988Q_2 v \quad (2)$$

$$N_3^0 = 1.91Q_2 v + 4.69Q_3 v \quad (3)$$

$$N_4^0 = 0.11Q_2 v + 0.31Q_3 v + 4.58Q_4 v \quad (4)$$

$$N_5^0 = (0.02Q_2 v + 0.04Q_3 v + 0.58Q_4 v + 3.61Q_5 v) \times 10^{-6} \quad (5)$$

Hence, for a given sampling period, we have the initial numbers for decay in terms of atmospheric concentrations.

Decay after sampling. The decay of activity after completion of sampling is developed by considering the decay and the formation from the parent for each particular isotope. The number of atoms remaining at any time, T, after cessation of sampling may thus be expressed in terms of the initial numbers for decay.

The alpha activity is the sum of the activity for RaA and RaC′

$$A(T) = \lambda_2 N_2(T) + \lambda_5 N_5(T)$$

Therefore for total alpha activity

$$A(T) = 0.2326N_2^0 e^{-\lambda_2 T} + (9.761N_3^0 + 11.016N_2^0) \times 10^{-2} e^{-\lambda_3 T} + (3.518N_4^0 - 9.761N_3^0 - 11.551N_2^0) \times 10^{-2} e^{-\lambda_4 T} \quad (6)$$

Terms with N_5^0 and $e^{-\lambda_5 T}$ are negligible.

Analysis of decay curve. The pro-

* As indicated in the first set of derivations, the assumption is made that the atmospheric concentrations of the daughters remain constant during the sampling period. This assumption is not the case, however, during the early period of ventilation. The concentrations change with time under conditions of ventilation until they reach their new low steady values.

TABLE 2—Emission Properties of Rn and Daughters

i	Element	Emission and energy (Mev)	$T_{½}$ (min)	$\lambda_i = \frac{0.693}{T_{½}}$ (min^{-1})
1	Rn	α, 5.49	5.508×10^3	1.258×10^{-4}
2	RaA	α, 6.00	3.05	0.2272
3	RaB	β, 0.65	26.8	0.02586
4	RaC	β, 3.15	19.7	0.03518
5	RaC′	α, 7.68	2.5×10^{-6}	2.77×10^5

TABLE 3—Laboratory Measurements of Daughter Ratios

Sample no.	Activity (cpm $\times 10^{-4}$) A(5)	A(15)	A(30)	Equilibrium ratios
1	7.42	5.15	4.67	1, 0.40, 0.22
2	5.02	4.15	3.72	1, 0.88, 0.54
3	4.67	3.91	3.46	1, 0.99, 0.65
4	6.98	4.60	4.40	1, 0.34, 0.12

cedure now is to analyze, in terms of the foregoing developments, any decay curve of total alpha activity observed during the first 45 min.

The method of analysis consists simply of determining the particular values of N_2^0, N_3^0 and N_4^0, in Eq. 6, that best fit our observed alpha-decay curve. Three values of the time T, 5, 15, and 30 min, are selected so as to be most nearly descriptive of the significant portion of our observed decay curve. Substituting these values separately into Eq. 6, we obtain

$$A(5) \times 10^2 = 7.459N_2^0 + 0.388N_3^0 + 2.951N_4^0 \quad (7)$$

$$A(15) \times 10^2 = 1.428N_2^0 + 0.863N_3^0 + 2.076N_4^0 \quad (8)$$

$$A(30) \times 10^2 = 1.077N_2^0 + 1.096N_3^0 + 1.225N_4^0 \quad (9)$$

To find solutions for a given observed decay curve, the observed activities in disintegrations per minute, for the times $T = 5$, 15 and 30 min, are substituted into Eqs. 7, 8, and 9. This set of equations is then solved for N_2^0, N_3^0, and N_4^0.

Having thus found the N_i^0, we may now substitute in Eqs. 2, 3, and 4 to obtain the corresponding concentrations

$$Q_2v = 0.335N_2^0 \quad (10)$$

$$Q_3v = 0.213N_3^0 - 0.407Q_2v \quad (11)$$

$$Q_4v = 0.218N_4^0 - 0.0240Q_2v - 0.0677Q_3v \quad (12)$$

The constant factor v, the rate of sampling in liters per minute, is known and can be inserted. However, it cancels out and need not be known if only the equilibrium ratios are desired.

If we consider RaA as the parent

$$Q_2^\infty = Q_2$$

$$Q_3^\infty = Q_2^\infty \left(\frac{26.8}{3.05}\right) = 8.787\, Q_2^\infty$$

$$Q_4^\infty = Q_2^\infty \left(\frac{19.7}{3.05}\right) = 6.459\, Q_2^\infty$$

Our final derived ratios are, therefore, the observed concentrations divided by the equilibrium concentrations

$$1.00,\ Q_3/Q_3^\infty,\ Q_4/Q_4^\infty$$

Thus, the set of ratios 1.00, 0.80, 0.65 would mean that, if RaA is considered as the parent, then RaB is present at 80% of its possible equilibrium level and RaC is present at 65% of its possible equilibrium concentration.

Accuracy of method. The accuracy of the derived equilibrium ratios for the daughters is limited mainly by the precision with which the total alpha activities at 5, 15, and 30 min can be observed.

The most obvious approach to this problem is to make counts of statistically adequate magnitude, correct for decay during counting if necessary, and use these observed activities in the formulas. This approach has the disadvantage of providing no indication of the extent to which random decay is an influence. To avoid this disadvantage, which may give a false impression of the accuracy of the observations, it is suggested that counts be made more frequently and a smooth decay curve then fitted to the observed data. During this counting process, an effort may be made to obtain especially precise counts at 5, 15, and 30 min. The 5, 15, and 30 min activities may then be taken from the fitted decay curve and used in the formulas.

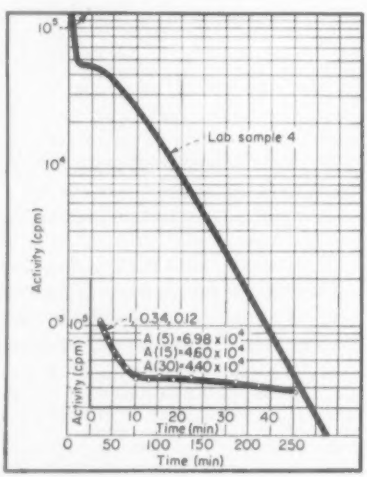

FIG. 2. Observed decay curve (inset shows early portion of curve)

For the studies reported in this paper, no special effort was made to obtain especially precise counts at 5, 15, and 30 min. The precision of results is entirely satisfactory for present purposes, as will be seen in the discussion of field results.

Conversion of calculated daughter concentrations to true atmospheric concentrations is not a simple matter, since several factors are not precisely known. The calculated concentrations are low due to losses in sample collection, counting losses resulting from dust-particle penetration into the filter paper medium, and self-absorption. Ventilation undoubtedly affects the mean particle size of the dust in the atmosphere, and thus may affect sample collection efficiency and losses due to penetration of dust particles into the filter paper. For the present, calculated daughter concentrations are converted to atmospheric concentrations on the basis of independent atmospheric radon samples obtained simultaneously with filter samples.

In addition to data presented here, research on this question is planned. It is believed that interesting information regarding collection and penetration characteristics of the molecular filter will result. The derived equilibrium ratios are relative figures and so are unaffected by these factors.

It is also noted that the foregoing

derivations assume the absence of significant concentrations of isotopes from other natural radioactive series.

Experimental Methods

Atmospheric samples are collected by drawing a specific amount (approximately 85 liters) of the atmosphere through a molecular filter (Whatman No. 41 filter papers may also be used). A hand pump has been used, since electric power is not usually available in uranium mines. The hand pump is operated at about 17 liters/min, and the sample collected for a period of 5 min. The filter paper is then at once removed from its holder and placed in a methane-flow proportional counter. The decay curve is developed over a period of 45 min and analyzed.

Laboratory procedure. For laboratory work, a closed radon box of 145-liter volume was sampled. The box contains a bed of rich uranium ore, which serves as the source of radon. During the 5-min sampling period, exhaust air from the hand pump was returned to the radon box. Five-minute samples collected from this box usually reflect daughter concentrations considerably below equilibrium, as expected.

Field procedure. Field samples were collected in a drift of a uranium mine and carried out of the mine to be counted. Since other counting means proved too inaccurate for our purposes, our laboratory model methane-flow proportional counter was mounted in a vehicle, taken into the field, and operated off a portable generator.

Atmospheric radon samples were collected in the field simultaneously with the filter paper samples. These samples were collected in standard 2-liter flasks and transported back to the laboratory for subsequent analysis by a method developed by the New York Operations Office of the Atomic Energy Commission.

Results of Laboratory Studies

The 5-minute filter samples, taken from the radon box, were counted in the methane-flow proportional counter. Since the volume of atmosphere sampled was more than half of the entire volume of the radon box, RaB and RaC were not usually found in equilibrium concentrations with RaA.

Table 3 gives results from four typical decay curves observed in the laboratory. Prior to taking samples 2 and 3, the box was agitated for several minutes and then the dust was permitted to settle for a period of an hour before sampling. Samples 1 and 4 were taken only after the box had been at rest for several days.

Figure 2 shows the decay curve observed for sample 4, with the early portion shown separately on an expanded time scale. This curve was developed over a relatively long period of time to provide information as to the observed half-life after various decay periods. For this curve, the observed half-life is about 45 min after 1 hr of decay. It then decreases to about 28.5 min after 6 hr, and approaches the 26.8-min value for RaB.

The data of Fig. 2 serve to illustrate the computations involved. The activities at 5, 15, and 30 min may be substituted into Eqs. 7, 8, and 9, to find the N_i^0. These initial numbers are then used in Eqs. 10, 11, and 12

$$Q_2v = 1.66 \times 10^5 \text{ atoms/min}$$
$$Q_3v = 5.01 \times 10^5 \text{ atoms/min}$$
$$Q_4v = 1.28 \times 10^5 \text{ atoms/min}$$

A knowledge of the actual rate of sampling, v, in liters/min, is not necessary in determining the equilibrium ratios, as this factor simply cancels out. However, v is needed to determine the concentrations Q_i, and so will be used here. For these studies, $v = 17$ liters/min, whence

$$Q_2 = 9.77 \times 10^3 \text{ atoms/liter}$$
$$Q_3 = 2.95 \times 10^4 \text{ atoms/liter}$$
$$Q_4 = 7.53 \times 10^3 \text{ atoms/liter}$$

These concentrations have not been corrected for geometry of counting nor for the over-all efficiency of sample collection and penetration of particles into the filter paper.

If we consider RaA as the parent

$$Q_2^\infty = Q_2 = 9.77 \times 10^3 \text{ atoms/liter}$$
$$Q_3^\infty = 8.59 \times 10^4$$
$$Q_4^\infty = 6.31 \times 10^4$$

Our desired equilibrium ratios are therefore 1, 0.34, 0.12. Thus, if RaA is considered as the parent, RaB and RaC were present at 34% and 12% of their equilibrium concentrations.

As the volume of the radon box is

TABLE 4—Daughter Concentrations in Samples from Mechanically and Naturally Ventilated Mines

*Sample no.**	*Ventilation rate (ft³/min)*	*Ventilation period*	*Calculated equilibrium ratios*	*Concentration (atoms/liter)*		
				RaA	*RaB*	*RaC*
2	natural	>one day	1, 1.01, 0.91	2.66×10^4	2.36×10^5	1.57×10^5
3	natural	~1,000 min	1, 1.10, 0.93	4.21×10^4	4.08×10^5	2.53×10^5
4	800	30 min	1, 0.34, 0.20	4.7×10^1	1.4×10^2	6.1×10^1
5	150	20 min	1, 0.69, 0.57	9.00×10^2	5.41×10^2	3.33×10^2
6	natural	~1,000 min	1, 0.96, 0.82	3.93×10^4	3.33×10^5	2.08×10^5
7	150	30 min	1, 0.89, 0.75	6.35×10^2	4.96×10^4	3.06×10^4
8	400	30 min	1, 0.81, 0.71	2.76×10^2	1.95×10^3	1.27×10^3
9	~30	45 min	1, 0.93, 0.80	2.70×10^4	2.20×10^5	1.40×10^5
10	300	30 min	1, 0.73, 0.69	8.10×10^2	5.16×10^3	3.60×10^3
11	800	30 min	1, 0.27, 0.33	5.0×10^1	1.2×10^2	1.1×10^2
12	natural	>one day	1, 0.86, 0.70	8.51×10^2	6.41×10^3	3.86×10^3
13	natural	>one day	1, 1.01, 0.89	6.70×10^2	5.97×10^3	3.86×10^3
14	natural	>one day	1, 0.90, 0.87	4.06×10^2	3.23×10^3	2.30×10^3
15	natural	>one day	1, 0.71, 0.50	7.3×10^1	4.6×10^2	2.4×10^2

* Samples 2–11 taken from Mine A. Samples 12–15 taken from Mine B at stations 560, 460, 250, and 100, respectively.

small, it is likely that the concentrations changed somewhat during the 5-min sampling period. Therefore, in the case of laboratory samples, the concentrations and equilibrium ratios probably represent only average atmospheric conditions during sampling to fair approximation. This is not the case, of course, for field samples, where the samples are quite small with respect to the surrounding volume of the mine drift.

Field Studies

Atmospheric samples were collected and analyzed in each of two uranium mines (referred to here as Mines A and B) in southern Utah.

In Mine A, the development drift studied was approximately 60 ft long, its junction with the main drift occurring at about 420 ft from the portal of the mine. This drift was about 6 ft high and averaged 6 ft wide. No men worked in this drift during the study.

Mine B is an abandoned gold mine. Preliminary tests indicate that it may be a source of uranium. Samples were collected in the main drift of Mine B at points 560, 460, 250, and 100 ft from the portal. The drift was about 6 ft high and averaged 5 ft wide. As evidenced by the use of smoke tubes, natural ventilation of the main drift was increasingly strong as one proceeded toward the portal from the interior of the mine.

The studies in Mine A included investigation of the effects of ventilation on the daughter concentrations and on the equilibrium ratios. Ventilation of Mine A was accomplished by means of a large-capacity blower mounted on a truck. Fresh air was delivered through 500 ft of 1-ft-diameter rubberized flexible ventilation tubing to a point 25 ft from the dead end of the development drift. Samples were collected at a location 5 ft from this working face, or 20 ft in front of the outlet end of the ventilation tubing. The rate of fresh air introduction was regulated by controls at the blower.

A total of 14 field samples were collected and studied. The basic data and the results of analysis of the decay curves from all samples are given in Table 4. The daughter concentrations are corrected for counting geometry, but not for losses due to penetration and self-absorption nor for the efficiency of sample collection.

Samples 2, 3, and 6 were taken in the early morning, and reflect undisturbed atmospheric conditions before any artificial ventilation was used in Mine A. Table 4 indicates that, under such conditions in this development drift, daughter concentrations may be expected to be at or near their equilibrium levels. This is also supported by the data for sample 9, the latter having been taken during ventilation at a rate that was essentially negligible.

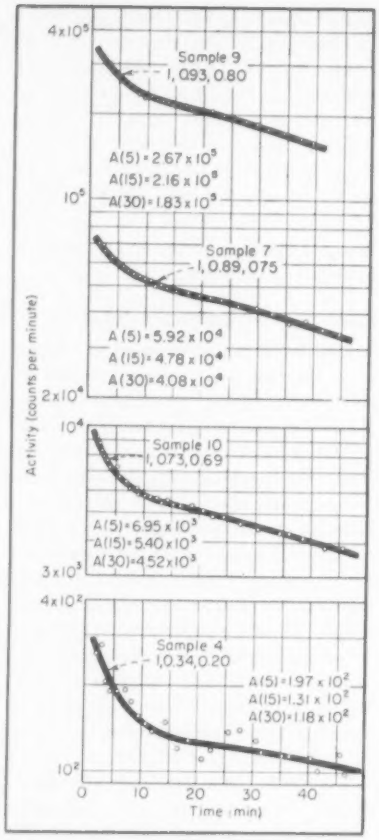

FIG. 3. Decay curves of field samples taken during ventilation

Figure 3 presents typical alpha-decay curves from samples taken during ventilation at various rates of fresh-air introduction. As indicated in Table 4, the ventilation rate for sample 9 was extremely low; Fig. 3 and Table 4 show that this rate was quite ineffective. Sample 7 shows significant effects from a somewhat higher rate of ventilation (150 ft³/min); the concentrations have been significantly reduced, and reflect some departure from equilibrium.

Sample 10 (Fig. 3) indicates the effects of a further increase in the rate of ventilation. The daughter concentrations are further reduced, as are the equilibrium ratios.

Sample 4 (Fig. 3) reflects conditions for the highest rate of ventilation used. The effects of the random nature of decay are more apparent in this case, due to the very low activity of the filter sample. To offset this effect, however, the decay curves become increasingly different in shape as the concentrations of the daughters depart from equilibrium. Hence, sufficiently precise data can be obtained from this decay curve.

Table 4 indicates that the concentrations are greatly reduced at this high rate of ventilation, and the greatest departure from equilibrium of the daughters is also observed. Thus, the hazards connected with working in this drift at the high ventilation rate are considerably less than the hazard estimated on the basis of observed reductions in radon concentrations.

Table 4 also indicates the results from samples collected at the designated locations in Mine B. Samples 12, 13, and 14 indicate near-equilibrium atmospheric concentrations of the daughters of radon. This is as expected since there was no appreciable natural ventilation at the corresponding sampling points. On the other hand, while no actual measurements were made, natural ventilation was observed to be very strong at the location for sample 15, which was taken at

TABLE 5—Rn in Mine Atmospheres

Sample no.	*Radon Concentrations*	
	μμc/liter	*atoms/liter*
3	10,300	1.82×10^8
4	58	1.03×10^6
5	240	4.24×10^6
6	10,500	1.86×10^8
7	1,570	2.78×10^7
8	142	2.51×10^6
9	6,550	1.16×10^8
10	235	4.15×10^6
11	50	8.8×10^5
12	180	3.18×10^6
13	165	2.92×10^6
15	60	1.06×10^6

TABLE 6—Rn Conc. (atoms/liter)

Sample	N_2^0 *(observed)*	N_1^0 *(calculated)*	N_1^0 *(observed)*
3	4.21×10^4	7.60×10^7	1.82×10^8
6	3.93×10^4	7.10×10^7	1.86×10^8
9	2.70×10^4	4.88×10^7	1.16×10^8

a point only 100 ft in from the portal and in a direct line with the portal. As a result, sample 15 indicates daughter concentrations considerably below equilibrium.

Accuracy of results. The precision with which the 5, 15, and 30 min observations are made controls the accuracy of the derived equilibrium ratios and daughter concentrations. No attempt was made during the studies reported to obtain especially precise counts at these times. As a result, the probable deviations in the results are greater than necessary.

It has been estimated, on the basis of a separate study, that any ratio reported may be in error by ± 0.04. The daughter concentrations reported admit of a corresponding degree of inaccuracy. For the purpose of estimating health hazards, these results are considered quite satisfactory.

Radon samples. Table 5 presents the results of the independent radon determinations made during the surveys of Mines A and B. Except in two cases, atmospheric radon samples were collected in standard 2-liter flasks simultaneously with the collection of the filter samples.

The method of analysis consists essentially of transferring a measured portion of the gaseous sample into an ionization chamber and, by means of a vibrating-reed electrometer, recording the current produced during a period of several hours. The results of this analysis are reported in micromicrocuries per liter, but have been converted to atoms of radon per liter to permit direct comparison with other data in this paper.

Table 4 indicates that samples 3, 6, and 9 reflect what are essentially equilibrium concentrations of the daughters of radon. Hence, we can safely assume that RaA was at equilibrium with radon in the atmosphere when these samples were collected. Therefore, for these samples, the concentration of radon can be calculated from the RaA concentration and compared with the values obtained by direct measurement (Table 6).

For these three samples, approximately 60% of the atmospheric daughters were not counted. This total loss can only be attributed to the combined effects of inefficiency of sample collection and penetration into the filter medium of some unknown fraction of the collected dust particles.

TABLE 7—RaA Concentrations in Samples from Mine A

Sample no.	*RaA concentration (atoms/liter)*			*Percent of equilibrium*
	Observed	*Corrected*	*Calculated**	
5	9.00×10^2	2.25×10^3	2.34×10^3	96
7	6.35×10^3	1.59×10^4	1.54×10^4	103
10	8.10×10^2	2.02×10^3	2.30×10^3	88
8	2.76×10^2	6.90×10^2	1.39×10^3	50
11	5.0×10^1	1.25×10^2	4.86×10^2	26
4	4.7×10^1	1.18×10^2	5.70×10^2	21

* From Rn concentration.

It is considered most likely that ventilation will cause the over-all efficiency of sample collection and counting to be reduced still further, but the extent of this effect cannot be evaluated as yet. For the present, therefore, in order that we may make some estimate of the degree of equilibrium for RaA, the assumption is made that the over-all percentage loss was essentially constant for all samples in Mine A. On the basis of this assumption, it is possible to show the general effect of ventilation on the degree of equilibrium for RaA. It is emphasized that the results of the calculations must be interpreted with caution.

Table 7 presents the calculations for the remainder of the samples taken in Mine A. The last column shows the percent of equilibrium estimated from the corrected RaA values and from the RaA values calculated from the measured Rn concentration. The samples are arranged in order of increasing rate of ventilation, reading downward (cf. Table 4).

As anticipated, it is apparent that the degree of equilibrium for RaA is directly and strongly affected by ventilation. Although the actual values in the last column of Table 7 are only a rough estimate, nevertheless the qualitative effect of ventilation is obvious—as the rate of ventilation is increased, the degree of equilibrium for RaA decreases accordingly.

Regarding the actual extent of this effect, it is believed that the over-all efficiency of sampling and counting was less than 40% in some cases, especially at the high rate of ventilation. As a result, the equilibrium percentages are probably too low, the error involved being quite small at low ventilation rates, but becoming increasingly large as the rate of ventilation is increased.

Based upon other information, it is believed that, for samples 4 and 11, the over-all efficiency was only about 20%. This would imply a degree of equilibrium for RaA of about 45% for these two samples, which is believed to be more nearly correct than the average of 24% shown in Table 7. It is also probable that the over-all efficiency increases toward 40% as ventilation is reduced, and that this 40% efficiency is essentially correct for samples 5 and 7.

Future Research

In the hope of obtaining further detailed information on the effects of ventilation and on analysis of samples, it is planned to continue this research with more specialized equipment.

The study of gaseous samples may yield additional information, especially with regard to the degree of equilibrium for RaA.

Studies of the collection efficiencies of various filter papers will be made in the laboratory and in the field. An attempt will also be made to evaluate the loss in counting due to penetration of dust into the filter medium.

* * *

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Radiation Exposure Survey of X-Ray and Isotope Personnel

A three-year survey of X-ray and isotope users shows that X-ray workers are subjected to considerably more exposure than isotope workers. The increasing number of clinics using isotopes emphasizes the need for training in safe procedures

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THE NUMBER OF WORKERS exposed to radiation in hospital clinical X-ray departments and radioisotope laboratories has increased as much as tenfold in some cases since our 1949 survey (*1*).

The millicurie concentrations of activity used in research laboratories have not increased. However, there has been an added number of diagnostic and therapeutic clinics using larger amounts of radioactivity.

X-ray laboratories have remained at about the same work level, but the tendency to utilize higher kilovoltage techniques for diagnostic procedures has, to some extent, increased the amount of scattered radiation. Thus, the possibility is increased of workers receiving a larger dose than with previous techniques.

The present method of monitoring is with DuPont special film, type 502, packaged in dental packs. This emulsion is the same as the most sensitive film contained in the packet used for the previous survey, DuPont 552-2 (*1*). The badge-type holder for the film packet used by this group is made of 1.0 mm of aluminum (shown in the illustration).* This aluminum holder contains a filter that enables the person evaluating the exposure to identify energy levels to which the film was exposed. In the holders used for X-ray laboratories, the filter is 1.0 mm of copper; for isotope laboratories, 1.0 mm of cadmium. Both filters are placed so as to shield approximately one-third of the film.

The film is worn for a period of one week on the worker's lapel, or on the outside of a laboratory coat or lead rubber apron. The films are developed by a standard procedure. The densities, as read on an Ansco Sweet (MacBeth) densitometer, are correlated with roentgens from established curves of density vs roentgen values (*2*). The need to revise these curves to include isotopes with wider energy ranges than previously reported is recognized, and work is in progress to bring them up to date.

* This is the type holder used by the New York Operations Office, Atomic Energy Commission.

X-Ray Departments

During the period from January 1, 1950, to December 31, 1952, 12,225 films were worn by a total of 275 workers in twelve X-ray departments. The results of the survey are shown in Table 1.

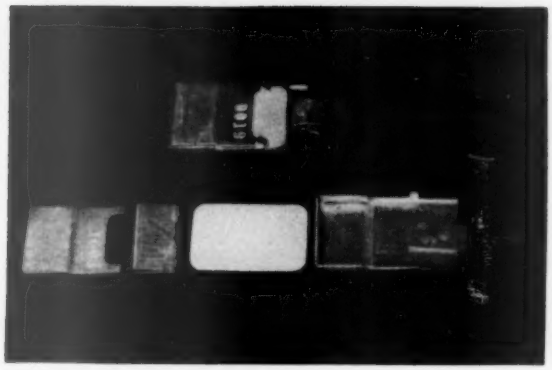
Over the three-year period, only 68 films out of the 12,225 total, or 0.56%, showed exposure in excess of the weekly permissible dose of 0.3 r (300 mr). A point of interest shown in Table 1 is the steady, yet slight, increase in the percentage of films showing exposure greater than 0.3 r.

TABLE 1—Survey of X-Ray Department Workers

	1950		*1951*		*1952*	
Total films	3,747		4,051		4,427	
No. workers	83		93		99	
Roentgen values	*No. films*	*% of total*	*No. films*	*% of total*	*No. films*	*% of total*
0–0.05	2,754	73.7	2,607	64.1	2,600	58.7
0.05–0.10	763	20.2	1,128	28.0	1,418	32.0
0.10–0.20	168	4.5	237	5.9	311	7.0
0.20–0.30	46	1.2	56	1.4	69	1.6
over 0.30	16	0.4	23	0.6	29	0.7

TABLE 2—Survey of Isotope Laboratory Workers

	1950		*1951*		*1952*	
Total films	8,520		10,136		10,291	
No. workers	163		196		221	
Roentgen values	*No. films*	*% of total*	*No. films*	*% of total*	*No. films*	*% of total*
0–0.05	8,494	99.7	10,090	99.54	10,234	99.43
0.05–0.10	13	0.15	24	0.24	27	0.27
0.10–0.20	4	0.05	9	0.09	11	0.11
0.20–0.30	3	0.03	7	0.07	8	0.08
over 0.30	6	0.07	6	0.06	11	0.11



ALUMINUM film-packet holder showing filter

TABLE 3—Survey of Films Worn by Clinic Nurses

	1951		*1952*	
Total films	65		173	
Roentgen values	*No. films*	*% of total*	*No. films*	*% of total*
0–0.05	41	63	89	51
0.05–0.10	13	20	49	28
0.10–0.20	8	12	23	13
0.20–0.30	3	5	12	7
over 0.30	0	0	0	0

Of the sixteen films in Table 1 showing exposure of over 0.3 r in 1950, six were between 0.3 and 0.4 r, eight were between 0.4 and 0.5 r, one was 1.2 r, and one was 1.4 r. During 1951, seventeen films were between 0.3 and 0.4 r, three films were between 0.5 and 0.6 r, two films showed an exposure of 0.9 r, and one film showed 1.0 r. During 1952, twenty films were between 0.4 and 0.5 r, three films showed between 0.5 and 0.6 r, and six films showed between 0.8 and 1.0 r.

It is interesting to note that for each of the three years the exposures in the 0.8–1.2 r range were received by technicians who had held children or aged people while they were radiographed. Films in the range 0.4–0.8 r were all traced to technicians who did not make proper use of existing barriers or were in the room at the time radiographs were made. Exposures in the 0.3–0.4 r range were untraceable but are believed to be due to a combination of the above-mentioned causes. No exposures above 0.2 r were received by technicians or roentgenologists doing either therapy treatments or fluoroscopic examinations.

In Table 1, a better representative picture of the radiation received by personnel is shown than in the previously published data (*1, 3*) because of the greater number of weeks each laboratory has been monitored. The shortest survey period included in these figures is for a laboratory that was monitored for eight consecutive weeks.

Radioisotope Laboratories

During the same three-year period, a total of 28,947 films were worn by 580 workers in research laboratories using isotopes. The ratio of exposure is the same as that reported in 1949. All of the research laboratories monitored by this method use less than 15 mc of radioactive material for procedures in any one week. The greatest percentage of the total materials used is of very short half-life and, therefore, does not constitute a serious hazard.

An analysis of the films worn by research laboratory personnel is shown in Table 2. During the three-year period, a total of twenty-three films showed exposure in excess of the weekly permissible dose of 0.3 r. The breakdown of the overexposures shows that for 1950 all six films were between 0.3 and 0.4 r and were worn by persons preparing isotopes from the initial stock shipment. During 1951, four of the six films overexposed were between 0.3 and 0.4 r and were due to the same preparation technique; the other two films showed between 0.4 and 0.5 r, the cause of the exposure being inexplicable by the persons wearing the badges.

Therapeutic Clinics

The isotopes used for therapy in the clinics surveyed were Au^{198}, I^{131}, and K^{42}. The total body radiation (gamma roentgens) received from these isotopes at 50 cm would be 0.096, 0.105, and 0.078 r/100 mc/hr, respectively, provided no additional shielding is employed by the workers (*4*).

Thus, it can be concluded that for a convenient length of time a nurse may stay within 50 cm of a patient who has been injected with 100 mc of either Au^{198} or I^{131}. Measurements conducted with an ionization-type survey meter of radiations emitting from a patient containing 100 mc of Au^{198} have established that a nurse can safely carry out her duties within the 50-cm zone for a period of 20 min each day without exceeding the maximum permissible exposure of 50 mr per day.

The number of nurses who have been surveyed by film has not been large enough to get a fair appraisal of the amount of radiation received. However, Table 3 has been compiled from 238 films worn for a period of one week by nurses attending therapy patients who had received between 50 and 150 mc of I^{131} or colloidal Au^{198}. In comparing Table 2 with Table 3, it should be kept in mind that, instead of an average of 5 mc per week of gamma-emitting isotopes used by workers in research laboratories monitored, there was an average of 250 mc per week used by personnel employed in therapeutic clinics. The low personnel exposure in Table 3 reflects the value of sufficient training.

From the data presented, it may be seen again, as in 1949, that the X-ray worker receives considerably more exposure than the isotope worker. With the increased use in clinical procedures of radioisotopes, the proper education and monitoring of personnel cannot be overemphasized.

* * *

The authors wish to thank Miss Ina Foster for her assistance in preparing part of the data for this paper. This work was done under AEC contract AT(30-1)-901 with the New England Deaconess Hospital.

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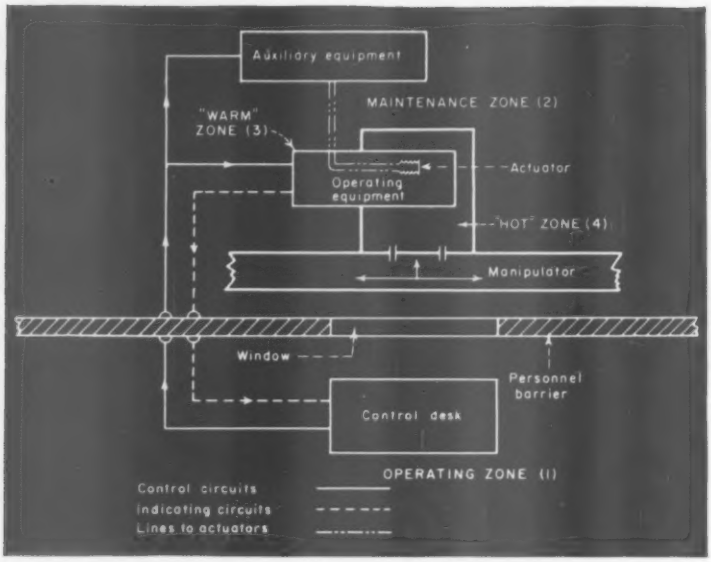

FIG. 1. Suggested compartmentation of area for weighing radioactive materials

Precision Balances for Radioisotopic Applications

Recently developed balances have achieved precisions to 1 ppm in weighing objects up to 5 kg. Remote operation and indication plus weighing-area zoning provide minimum exposure of parts and personnel to radioactivity

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WEIGHING PROCEDURES applied to radioactive materials, if the radiation is other than alpha particles, must afford sufficient protection to the operator. In addition, instruments combining high load capacity with high accuracy are needed.

Divergent trends in the development of weighing instruments have created a gap in terms of capacity and sensitivity,* with industrial machines at one extreme and analytical balances at the other. This relatively undeveloped region ranges roughly in capacity from 200 to 10,000 gm and in precision from 1 part in 1,000,000 to 1 part in 50,000.

It is primarily in the production of radioactive materials that specially designed balances can be utilized to advantage at this time. Weighing operations may be intermixed with steps in the processing of radioisotopes or included as part of their inspection

*"Sensitivity" is used synonymously with the terms "sensibility" and "sensitiveness."

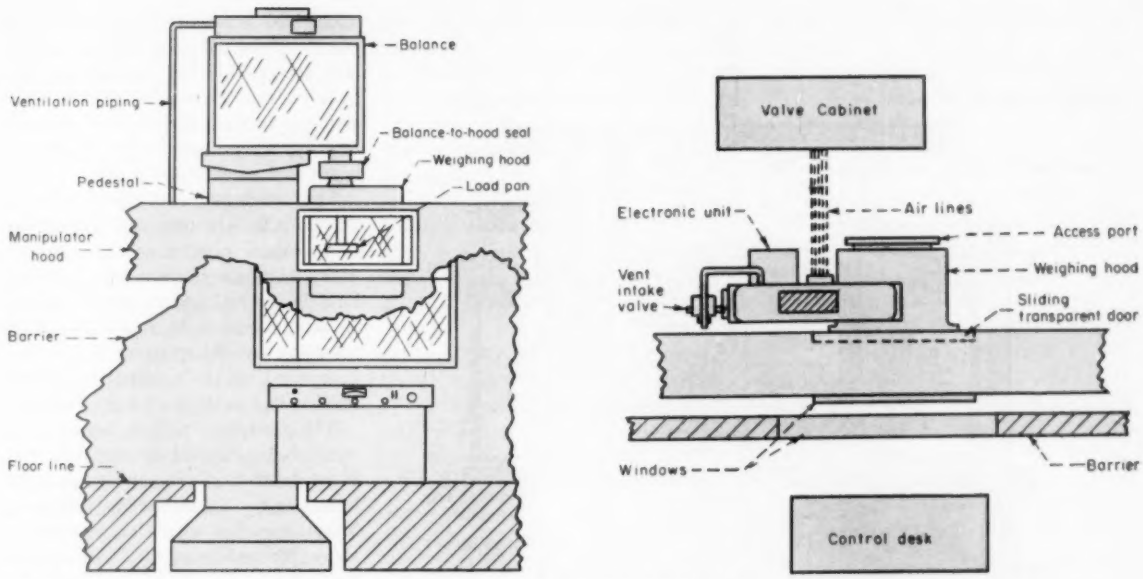

FIG. 2. Integrated system for weighing objects by remote handling. At left is front view and, at right, schematic layout

at appropriate points, as the following:

1. Weighing of relatively large masses for accountability purposes.
2. Weighing to accompany cutting or machining of solids to size.
3. Weighing of objects under water or other liquid.
4. Weighing of solids, liquids, slurries, and dry mixtures in air or inert gas.
5. Weighing associated with the precision determination of density of irregular solids.
6. Over-and-under weighing or weight-loss measurements where the loss is a small percentage of the total weight of a large object.
7. Weighing of small amounts of material in heavy containers, i.e., large tare.

A balance suitable to accomplish these purposes must have high-capacity, high-accuracy measurement capabilities. It must be remotely controlled. A self-contained means of checking accuracy should be included. In addition, the balance mechanism must be internally protected against loading shocks. Careful integration with external manipulators is required to insure proper indexing and handling of the load. Means should be provided to reduce the probability of contamination of the working parts.

To meet these needs for cases where the use of standard equipment is precluded, the remotely controlled balances described here were constructed in three ranges: a medium-precision balance with an 8-kg capacity, accurate to ± 0.1 gm; a higher-precision balance with a 5-kg capacity, accurate to ± 0.01 gm; and a balance with a capacity of 500 gm, accurate to ± 0.001 gm. Later models were built with accuracy tolerances one-half of those cited.

Work-Area Zoning

Compartments or "hot" zones can be set up whereby successive subdivisions provide increasing safety to personnel and permit minimum contamination of parts.

Figure 1 shows typical operating equipment, together with accessories, connected to the hot zone. While highly protective clothing would be required to work on apparatus in Zone 4, fewer restrictions would be encountered when replacing a vacuum tube in Zone 2. Were a person to operate the equipment from Zone 1, his environment would be the same as that of any clean, air-conditioned office.

Remote electropneumatic control and electrical indication make possible safe piercing of personnel barriers by use of bulkhead pressure-tight connectors. Likewise, a closed pneumatic system can be maintained between Zones 2 and 3 by means of air lines from the auxiliary equipment to bellows actuators within the operating equipment.

Other considerations in the design of a remotely operated weighing system are:

1. Capacity and accuracy tolerances required at each weighing station.
2. Process flow and permissible hold-up time for weighing operations.
3. Location and conformation of adjacent equipment.
4. Ventilation system available for tie-in with balances.
5. Type and location of facilities such as power and air.
6. Use of special maintenance techniques, if required.

Configuration of Equipment

The several balances built, and now in operation, are similar in details of construction and method of control. The general configuration of the equipment is shown in Fig. 2.

A typical balance sets on a sub-base and leveling unit, which in turn rests on a massive pedestal. The operations required to perform a weighing are all remotely controlled from a desk located on the other side of a personnel barrier.

The balance is connected to its weighing hood by means of a seal unit (Fig. 3). The seal serves to isolate the balance from the rest of the system except during weighing, to provide

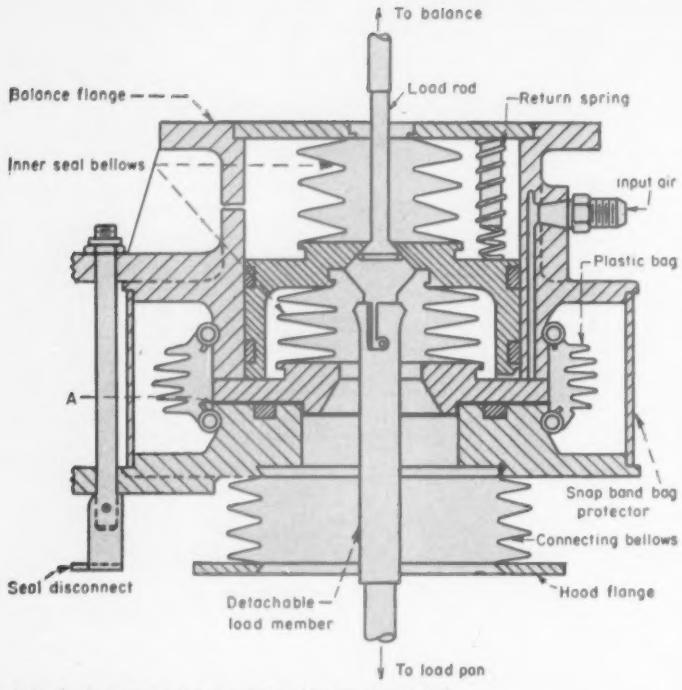

FIG. 3. Balance-to-hood seal unit (in closed position)

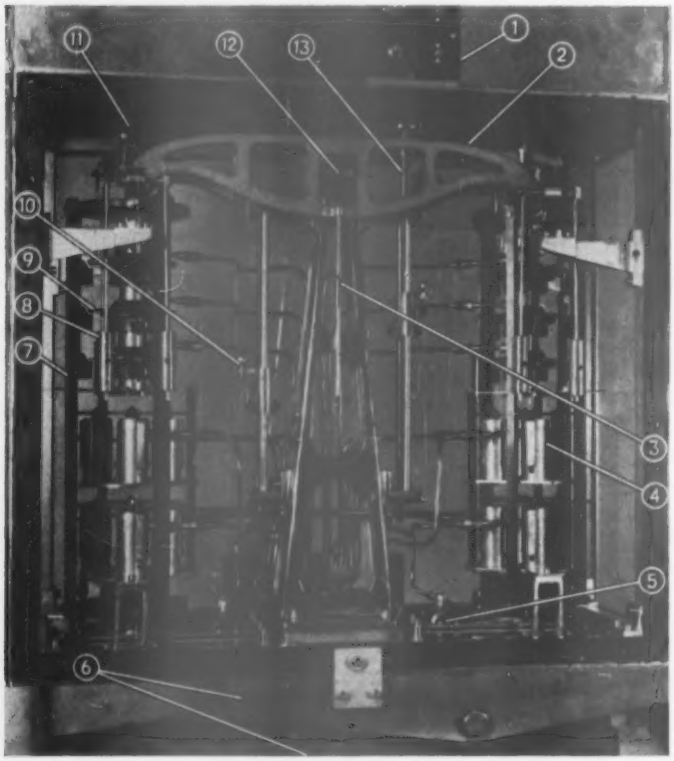

FIG. 4. Substitution-weighing balance. Parts are: (1) sensing unit, (2) beam, (3) gravity-ball sensitivity adjustment, (4) tray unit weight assembly, (5) stabilizer (locking) assembly, (6) sub-base and leveling assembly, (7) weight cage, (8) stabilizer pendulum, (9) unit weight, (10) chain poise, (11) riser to capacitor plate, (12) flexure plate, (13) poise-drive screw

additional locking protection for the balance during loading and unloading, and to provide for disengaging the balance from the weighing hood. For removal of the balance, load member is dropped and two halves of the seal separated at cleavage line A.

The weighing hood, complete with access ports, windows, and connections for pressure gage, ventilation intake, and exhaust, is in turn attached to a long hood which houses a manipulator. A sliding, draft-tight door between the manipulator and weighing hoods may be opened by the manipulator during loading and unloading of the balance.

The electronic unit is housed in a small box attached to the pedestal. It contains a power supply, an oscillator, and a vacuum-tube voltmeter. These, together with a sensing unit in the upper section of the balance, comprise the circuitry for remote indication of the beam equilibrium position.

The solenoid-valve cabinet, which converts electrical sequencing to pneumatic actuating, is located conveniently near the balance. Air lines in conduit are connected between the balance and the valve cabinet. The cabinet is equipped with a filter, regulator and gage, and a safety valve.

Balance Design

The balance is of the equal-arm beam type. The lower section, with its gasketed Plexiglas plates removed, is shown in Fig. 4. The rear cover plate is notched to accommodate an air-connection terminal block. From this block, lines from the valve cabinet are distributed internally to the bellows-actuating units.

Fulcrum and bearings. An optically flat fulcrum-bearing block made of boron carbide is supported by the fulcrum stand. The beam assembly, by means of the fulcrum knife-edge, rests on this bearing. The cast-magnesium alloy beam, designed for minimum weight and minimum deflection under load, also contains the two terminal pivots. All three pivots are made of tungsten carbide. The two sides, which form the knife-edge, are ground optically flat. The fulcrum pivot is mounted solidly at the beam center, while the terminal pivots are adjustably mounted for accurate alignment with the fulcrum pivot. This combination of pivot and bearing sustains very high loads without appreciable effect on the sensitivity.

Relative motion between the beam and fulcrum stand is checked by means of a flexure plate (Fig. 5) without restraining pivot action. The plate consists of two small blocks connected by a thin ribbon of low-hysteresis, high-strength alloy. The plane of the ribbon is adjusted to lie exactly on the axis of rotation. Two flexure plates are operated in parallel at each end of the three knife-edge assemblies. At the fulcrum, the plates prevent movement of the beam in a horizontal plane. The beam and cage supports are thus fixed relative to each other.

Weights and cage assemblies. The aluminum-alloy weight cages are suspended from the ends of the beam.

The unit weights are calibrated standards held in position within the confines of each cage by means of a bellows-housing assembly on which the weights are stacked. When a weight is lowered by admission of air to its corresponding spring-loaded bellows, it is transferred to the stepped brackets on the cage assembly and thus to one end of the beam. When the air is exhausted, the spring action returns the weight to its former position. Valves can be adjusted so that the weights are lowered very gently indeed; in this way, loading is regulated independently of the operator's "touch" at the controls.

On balances designed for substitution weighing, there is a full complement of unit weights associated with each cage. For direct weighing, a full set of weights is used only on the weigh end; one or two check weights are available on the load end of the beam.* The weights are highly polished stainless-steel disks with central holes for locating on the lifters.

Load-saddle stabilizer pendulum systems are provided that interconnect the terminal bearings and the top gimbals of the cage assemblies. The center of gravity of the terminal-bearing block lies above the knife-edge; thus the assembly is in itself unstable. It is greatly stabilized, however, by the rigid attachment of a four-way pendulum system to the saddle block. The pendulums act as a unit and are accurately plumbed parallel to the load axis by horizontally adjustable counterpoises. The weight cage is then suspended by additional knife-edges from the stabilized load saddle. The result of this arrangement is the elimination of equivalent zero shifts due to terminal-bearing displacements whenever uneven seating of the unit weights causes the weight cage to hang slightly out of plumb.

A swinging cage is stabilized by a pneumatic actuator that, in the closed position, causes locking pins to engage conical holes in a block attached to the bottom of the cage assembly. These pins are carefully adjusted so as not to strain the beam structure. In this manner, the beam and both cages are locked as a unit. A load rod is attached to the bottom inner gimbal ring of one of the cages. The rod passes through the balance floor and the seal unit, and terminates in a load pan or equivalent load-lifting device (Fig. 3).

Beam-movement indication. Risers at each end of the beam extend into the upper section through holes in the top casting. The risers terminate in circular plates that, in combination with like plates fixed to plastic insulating housings above, form variable parallel-plate capacitors. (Although the risers penetrate the top barrier, the compartmentation against contamination is still preserved in that the housing containing the capacitors is sealed and forms simply an extension of the barrier into the upper section.)

Motion of the beam causes differential changes in the air gaps of the capacitors. These, with additional fixed capacitors, constitute a bridge across which is impressed an r-f voltage from the oscillator below. The two resulting r-f voltages, which vary with the beam action, are rectified in the sensing unit, and the error signal is fed to a d-c vacuum-tube voltmeter.

The output of this circuit is delivered to a zero-center microammeter located on the control desk. A resonant filter is provided in the sensing unit to insure that the voltage peaks applied to the bridge system are symmetrical. The indicating circuit possesses sufficiently high sensitivity and stability to establish the necessary fiducial conditions for the movement of the beam.

Poise motor. The poise-drive mechanism is also located in the upper section of the balance. A small reversible motor powers a drive shaft that penetrates the top barrier by means of a shaft seal. A spline on the shaft engages one of a pair of driven screws, each of which carries a threaded block. The screws are so geared that one block goes up as the other goes down.

Two chain poises each have one end suspended from pivots on the carrying blocks; the other ends are similarly attached to the beam at equal distances

* With analytical balances, it is conventional for the left pan to receive the object to be weighed and the right pan the weights. However, the sense of the remotely operated balances is fixed by the mechanism. While the operator knows from the indication whether the load or weigh end is heavy, he may lose the significance of right- or left-handedness due to the orientation of the equipment behind a barrier and thus out of sight.

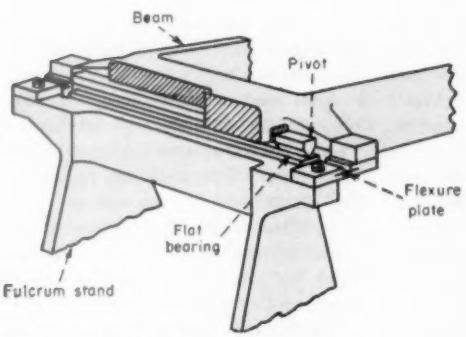

FIG. 5. General design of flexure plate

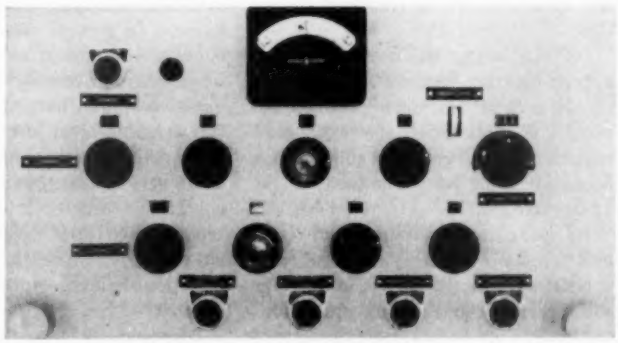

FIG. 6. Typical control desk for substitution-weighing balance

from the fulcrum. This arrangement results in a double-acting poise that extends the weight range to the smallest desired increment.

The poise motor is controlled in speed and direction from the desk. The motor also drives a Selsyn transmitter whose receiver is geared to a reset-type counter in the desk. When the poise is calibrated, the counter is read in grams and decimal fractions thereof.

Operating controls. A typical desk used with a balance designed for substitution weighing is shown in Fig. 6.

Two banks of dial selector switches, one for each set of unit weights, are used to sequence the solenoid valves for the actuators. Combinations of unit weights may be selected in decreasing order from left to right.

All dials are in grams. The last place on the poise counter is equivalent to 1 mg. The total value of the unknown load is read straight across the dials and can be recorded at any time.

On the larger balances, kilograms appear on the first dial, hectograms on the second, and dekagrams on the third. In this case, the least unit weight equals 10 gm, finer subdivisions being available on the poise rated at 10.00–0.01 gm.

By means of a switching and time-delay relay system, the motor and generator fields are energized only for short periods during balancing. Consequently, no substantial amount of heat is generated, which, transmitted to the beam, would cause uneven expansions of the arms.

The desk may also contain switches that allow interlocking of balance circuits with those of other equipment. This may be desirable for protection of the balance during loading.

Additional protection is provided in case of failure of the power or air supply. The balance fails safe completely—weights unload, the beam and cages lock, the seal closes, and the ventilation condition is reestablished.

Other desk switches shown in Fig. 6 control the functioning of the stabilizers, seal and ventilation system.

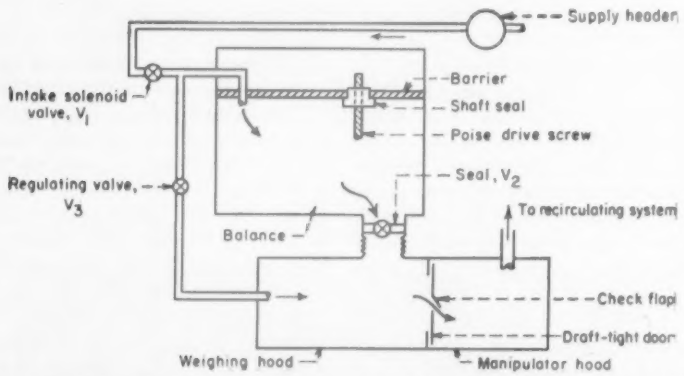

FIG. 7. Typical ventilation system. Valve V_3 establishes pressure drop between balance and weighing hood when seal V_2 is closed. Not-weighing conditions: V_1 open, V_2 closed, door closed, slight bleed through flap. Weighing conditions: V_1 closed, V_2 open, door closed, balance and weighing hoods stagnant

Ventilation System. A balance ventilation system in its simplest form is shown in Fig. 7. It is a part of the main building system in that the balance intake is connected to a header supplying clean or recirculated air or other medium.

The medium passes from the balance to the weighing hood, whose outlet is attached, through filters, to the exhaust. In certain cases, where loads contain contaminating dust, it may be necessary to provide additional means to purge both the balance and the weighing hood in proper sequence. The main requirement is that, in whatever system used, the pressure conditions are such that flow or tendency to flow (when the seal is closed, for example) is always in the direction: balance → weighing hood → exhaust.

Damping. The balances contain no special means for damping.

A slight amount of air damping is supplied by the cushioning effect of the parallel-plate capacitors. The motion of the beam is followed by the indicator pointer (through several elements of the telemetering system) to within an estimated linearity of about 0.2%. Therefore, the method of swings is applicable in determining the index of equilibrium of the balance.

On the other hand, decrements are such that oscillations will approximate the null position in 60–90 sec, depending on the mechanics of the beam in use.

A skilled operator can subdue the deflections even more rapidly by jogging the poise-motor switch in such phase as to buck the swings.

Pedestal design. It is necessary to mount a 200-lb balance having quasi-seismometric properties when it is surrounded by vibrators, pumps, blowers, etc., in a process line. However, it is virtually impossible to predetermine the bands of frequencies likely to occur in such a complex system.

It was decided to use as much mass as possible. Several tons of reinforced concrete were used in a column whose footing flared beneath the building floor to provide a substantial bearing area. This pedestal was isolated from the floor, and connections between the balance and weighing hood were made flexible.

In spite of this, it was discovered that a large compressor outside the building was transmitting vibrations through the earth of sufficient amplitude to shock-excite the balance into complex modes of oscillation. The response to this type of excitation was eliminated by means of the load-saddle stabilizer pendulum systems.

Operation

The sequence of steps involved in the direct weighing of an object begins with the balance locked, the balance-ventilation system on, and all controls at zero.

After warmup of the electronic components, the electrical and mechanical "zeros" of the system are brought into agreement. The hoods are stagnated; the seal and stabilizers are unlocked. The initial balance condition of the beam is established by moving the poise to give a null indication and resetting the counter to zero.

The balance is then locked and the unknown load placed on the pan by the

manipulator. The weight of the load is estimated in round numbers, and the left unit-weight dial set to a reading below this value. (The sense of the beam is such that when the load end is heavy, the balance indicator swings to the right.)

The balance is again unlocked. If the indicator pointer is to the left of zero, the dial setting is decreased until it moves to the right. In general, the dial having the largest doubtful increments is turned so as to increase the number of unit weights applied until the pointer swings to the left, then backed off one step. This is repeated for remaining dials in succession until the setting of the smallest applicable unit weight leaves the pointer to the right of zero.

Final balance is obtained by turning the poise control so as to cause the pointer to approach the null position from the right.

To reduce the time of hold-up in the weighing hood, the load may now be removed, the steps for protection of the balance and restoration of the ventilation conditions paralleling the withdrawal process. Dial and counter readings are recorded and the initial equilibrium condition checked. Individual unit-weight corrections are applied in conjunction with others, such as for buoyancy, and the true mass of the load is computed.

The difference in operating characteristics between these balances and those of standard design is soon apparent. Perhaps the greatest distinction is that considerably less time than usual is spent in bracketing the unknown weight value. Dialed selection and maximum economy of application of internally available weight combinations make the remotely operated balances capable of relatively rapid response.

Maintenance

Resistant materials are used wherever the threat of corrosion exists. Although great effort is made to keep the inner parts of the balance clean, it is an inescapable fact that a hole is necessary through which the load rod must pass into the hood below. The seal, however, provides a block to the entry of contaminated particles at all times except during the short period necessary for weighing.

Work may be done in place on all of the components in the upper section. Maintenance is also possible within the lower section where accessibility can be had with simple tools. For major work, e.g., on setting arm ratio or range of the pivots, the balance should be removed and replaced with a spare unit lest such delicate adjustments, made under difficult working conditions, take excessive time and jeopardize the continuity of the line operation.

The load pan may be detached within the seal (see Fig. 3). After external connections are broken, the balance is lifted and a plastic sleeve, still joining the bottom of the balance and the top of the weighing hood, is sealed off and cut. The balance may then be removed.

Performance

It was important to establish as high a degree of reproducibility as possible. This was done by accurately adjusting key elements of the beam structure. Erratic effects caused by friction and zero shifts due to hysteresis in flexure plates and springs were minimized. Efforts were made to eliminate adverse behavior resulting from drafts, temperature changes, vibration, and static electricity.

Calibration. Once made sufficiently sensitive over the load range and capable of maximum reproducibility, the balances then required final calibration.

The chain poises were sealed against appropriate standards. Ultimate accuracy was realized in terms of the unit weights. The complement in each balance comprised a set of standards, the weight determinations from which were better by one or two decimal places than the accuracy required of the balance. In this way, the instruments could be used either for relative weighing, or absolute weighing by application of weight corrections supplied by the National Bureau of Standards.

On the direct-weighing balances,* the internal check weight on the load end was balanced against the unit weights for an occasional test of the calibration; from the desk position, check readings were obtained and later used in calculating a correction factor to be applied to subsequent readings whenever errors resulting from arm-length inequality exceeded the specified tolerance.

With substitution-weighing instruments, excellent consistency between readings could be expected. When air buoyancy and other corrections were applied to the results, the absolute-weight values obtained for the test loads were in very close agreement with those certified by the Bureau of Standards.

Test results. The performance was indicated in the tests of two of the balances.

With loads up to its capacity, a 5-kg instrument gave repeated weighings to within 5 mg over a test period of several days.

A series of readings near top capacity on a 500-gm balance yielded the following data: average deviation from the mean, 0.0005 gm; reliability of the mean, 0.00014 gm; probable error of a single reading, 0.00047 gm. Thus, precisions in the order of 1:1,000,000 were realized.

Design Limitations

Certain limitations of the present design apparently resulted in a performance plateau in the region of precision noted earlier.

The bearings and pivots were capable of very large loads. Beyond a point, however, the bearing material appeared incapable of high enough polish to extend the degree of precision appreciably.

A poise of several chains in parallel, each with fractional parts of a link staggered over the total number of chains, was originally used in the larger balances. So much uncertainty developed due to friction between large links at the turnover points that it was necessary to install metal springs. Made of extremely low-hysteresis alloy, these springs, operated in linked pairs on either side of the beam, were capable of excellent linearity to about 1:2,000 in themselves. When they were used in a poise rated at 10 gm, it was possible to obtain, on a 5,000-gm balance, sensitivities (sensibility reciprocal) to 5 mg per division.

Stability criteria were two-fold, one mechanical and one electrical. The necessary conditions for stable mechanical equilibrium were well known from the literature (*1*, *2*). In the balances under discussion, the sensing of the beam action was accomplished by the variable parallel-plate capaci-

* This procedure minimizes the occasion for arm ratio adjustments when, after placement in operation, the equipment becomes exposed to radiation or contamination.

tors. Since the resultant electrostatic forces were along the same axis as those measured due to the applied loads, and, furthermore, since those differential forces were reciprocal power functions of the axial distance, great care had to be taken to space the plates far enough apart to counteract the instability inherent in the arrangement. This required a highly sensitive as well as stable detector circuit.

Finally, the balances were operated in surroundings where the ambient temperature was well stabilized.

Future Design Possibilities

Without altering the basic design, a number of improvements may extend the precision of these instruments to the order of 1:5,000,000 and, at the same time, further increase their life.

Experiments have been made which give the following items of investigation considerable promise:

1. Temperature stabilization by control, insulation, and radiation shielding.
2. Improved design of flexure assemblies and more highly polished bearing materials of high-load capacity.
3. Improved geometry of the detector arrangement.
4. Development of bellowsless actuators.
5. Extension of the poise-spring technique to balances of low capacity, e.g., 500 grams, whereby the exceptional linearity and repeatability of quartz springs could be realized.

By means of these improvements, it is likely that the ranges and precisions of the balances could be broadened to include such ratings as 5,000–8,000 gm capacity, accurate to ±0.001 gm; or 500-gm capacity, accurate to ±0.0001 gm.

In recent years, at least, progress in materials and methods has resulted in commercial* and special balances of greater capacity and precision. Remotely-operated balances can measure in the 5,000-gm load range with a precision of 1:1,000,000. In the other direction, the quartz microbalance (*3*) can achieve reproducibilities in the order of 0.03 μg at 300-mg capacity.

* For example, the Metrogram, made by H. A. Hadley Associates, Inc., is a bench-type balance in which the bearing and flexure plate design, and detector system of the remotely operated balances are combined with the Roberval principle to result in a high-capacity instrument of greater accuracy than was heretofore obtainable. This balance could be equipped with remotely operated weight loaders and weigh loads up to 20,000 gm to the nearest 50 mg.

To extend the extremes further toward higher capacities on the one hand and to greater precisions on the other, future balance design may have to move in such a direction that, after the appearance of diminishing returns in the form of refinements of materials and precise fabrication of parts, new systems are invented that marry the most desirable qualities of the high load-sustaining type to those of the microbalance.

Appendix

Definitions. The terms sensitivity, precision, and accuracy are often confused.

The sensitivity of an equal-armed balance is a function of the mechanical properties of the beam. It should be expressed as a ratio, such as millimeters deflection per unit excess weight or milligrams per scale division (sensibility reciprocal).

The reproducibility of the balance is a measure of its precision. In a series of readings, the precision of the result is the best numerical expression of its reliability after elimination of all known sources of error.

Accuracy involves the degree of concordance between the measured weight of an object and its true weight (*4*).

Direct and substitution weighing. For direct weighing, the unknown weight is placed on the load-end pan and balanced by the unit weights plus poise on the weigh end. The accuracy depends on the error due to arm-length inequality. From moments about the fulcrum, total weight is

$$W_L = [W_A + (\pm d_A) + (\pm P_1)] \times [(a + e)/a]$$

where W_L = weight of the load, W_A = sum of weigh-end dial readings, d_A = algebraic sum of corrections to W_A, P_1 = poise reading, a = length of one arm, $a + e$ = length of other arm.

To evaluate beam-ratio error, a weighing using the built-in check weight on the load end is necessary. Beam fractional error e/a is given by

$$\frac{e}{a} = \frac{d_x - d_y - P}{Y + d_x + P}$$

where Y = sum of unit-weight dial reading to balance check weight, d_y = algebraic sum of corrections to Y, X = sum of check-weight readings, d_x = algebraic sum of corrections to X, and P = poise reading associated with Y.

Two variations of the substitution weighing method may be used.

In the first, the balance is zeroed with both sets of unit weights initially in their unloaded positions. With unknown weight on load pan, a balance is obtained with weight-end weights and poise, and the poise reading, P_1, is recorded. Then the unknown is removed. Without changing weigh-end dials, load-end unit weights are substituted and balanced with the poise to the same equilibrium point as in the previous step, and the new poise reading, P_2, is recorded. The unknown weight is obtained from

$$W_L = [W_R + (\pm d_R)] + [(\pm P_1) - (\pm P_2)]$$

where W_R and d_R are the dial readings and corrections, respectively, of the *load-end* weights.

The second variation requires only one loading and unloading. The beam is preloaded on both ends with unit weights of the same nominal value, but higher than the estimated weight of the object; the difference in weight corrections is cancelled by obtaining a balance condition and resetting the counter to zero, i.e., $P_1 = 0$. Then place the unknown weight, W_L, on the load-end pan; *remove* load-end weights until the original balance condition is restored. Record poise reading, P_2. The weight of the load is then

$$W_L = [W_R + (\pm d_R)] - \{[(U_R + (\pm D_R)] - [\pm P_2]\}$$

in which $[W_R + (\pm d_R)]_s$ = corrected preloaded load-end weights, and $[U_R + (\pm D_R)]$ = corrected load-end weights subtracted.

* * *

The author is indebted to Messrs. H. A. Hadley and L. D. Singleton of H. A. Hadley Associates, Inc., manufacturers of the equipment, for detailed design information, assistance in tests and many valuable suggestions. He is also grateful to Mr. D. E. Norgaard of the General Electric Research Laboratory for the design of an improved electronic circuit and to those in the General Engineering Laboratory who aided in the over-all development.

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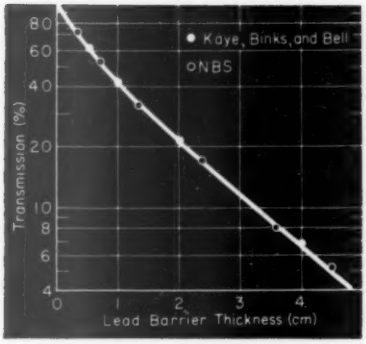

FIG. 3. Attenuation coefficients, nonmonoenergetic (Ra) source, narrow-beam (*15*)

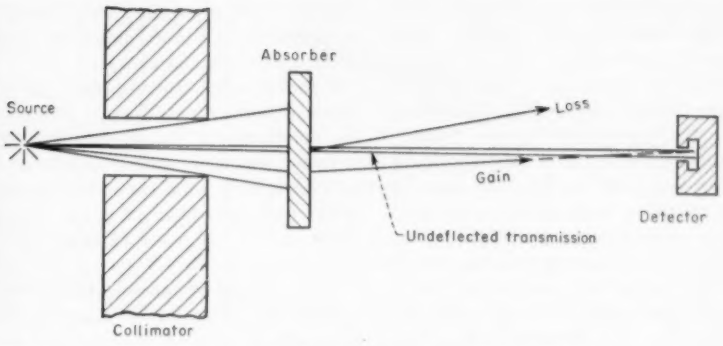

FIG. 4. Arrangement for measuring broad-beam attenuation coefficient

Gamma-Ray Attenuation

PART II

ANALYSIS OF PENETRATION

How to analyze gamma-ray penetration to determine attenuation coefficients and how to use published data in shielding calculations is described here. Basic interactions were discussed last month in the first of this two-part series

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A GAMMA-RAY PHOTON often experiences as many as 10 scattering processes before its eventual absorption. The direction of propagation thereby becomes increasingly random, and the initial straight penetration tends to go over into a diffusion process.

The penetration of gamma rays through a homogeneous medium of infinite extension is rather well understood. Much detailed information is available on this subject (*12–14*). But, when it comes to solving specific problems, one may expect to have to do a certain amount of adaptation of published data (see *Available Results of Calculations*). In addition, there is only meager understanding of the effects of inhomogeneities in a material and of boundaries between materials (these effects are not always large).

The information given in this concluding part of a two-part article pertains to gamma-ray propagation through homogeneous media of infinite extension, except where noted.

Pertinent Physical Effects

The interaction processes experienced by gamma rays give rise to a variety of "secondary radiations," e.g., scattered gammas, electrons ejected by photoelectric effect, etc. (see *Types of Processes* in Part I).

The gammas emitted directly from a source are called "primaries." For primary gammas up to 10 Mev, the secondaries that contribute much to penetration are themselves gammas (of lower energies), since secondary electrons do not travel far and secondary neutrons are few in number. Therefore, the study of gamma-ray attenuation deals with photons of various energies, even where the primaries are monoenergetic.

Filtration. Photons of different energies traveling together through an absorber, e.g., in a "narrow-beam"

attenuation experiment (Fig. 1*) with a non-monoenergetic source, have different probabilities of experiencing interaction processes. The gammas with higher interaction probability (i.e., the less penetrating, or "softer," ones—which usually are those of lower energy) are removed from the beam, in the course of penetration, faster than those with lower interaction probability. Thus penetration to deep layers of the absorber has an effect of "filtration" that selects gammas with low probability of interaction (i.e., the "harder" component of the initial beam). Accordingly, the successive layers of an absorber attenuate the beam by smaller and smaller fractions. The semilogarithmic plot of intensity vs thickness, which is a straight line for monoenergetic gammas in Fig. 2, has a decreasing slope (corresponding to a decreasing average value of the absorption coefficient, μ) for a non-monoenergetic beam in Fig. 3.

Broad-beam attenuation. In an attenuation experiment free from the "narrow-beam" limitation (see Fig. 4, in which the aperture of the collimator of Fig. 1 has been greatly increased), the loss by scattering of some gammas initially aimed at the detector is compensated in part by the deflection toward the detector of gammas initially directed otherwise.† Therefore, one finds a lower attenuation under "broad-beam" than under "narrow-beam" conditions, i.e., a spuriously low apparent value of the absorption coefficient.

As the absorber thickness increases, the "gain" derived from the "broad-beam" condition becomes comparatively smaller (owing to the increased chance of multiple interaction processes). Therefore, the apparent value of the absorption coefficient goes up with increasing absorber thickness, as shown by the increasing slope of the plot in Fig. 5. It approaches the value of the "narrow-beam" coefficient without ever attaining it. This increase in apparent value of absorption coefficient may not hold when the initial energy exceeds the minimum point of the absorption coefficient curve.

Notice that the "broad-beam" effect yields downward curvature, whereas the curvature of Fig. 3 due to the filtration effect is upward. Concurrent departures from a monoenergetic source and from "narrow-beam" condition tend to compensate and may fail to be observed.

Accumulation of secondaries. Not only in the "broad-beam" experiment, but quite in general, the presence of secondary scattered gammas heavily influences the whole process of gamma-ray penetration.

Compton scattering is, on the whole, the most frequent process for medium-energy gammas in the range of 0.1–10 Mev, especially in low-Z materials. A photon may easily experience 10 successive Compton processes before its eventual outright absorption, which most frequently occurs in a photoelectric process. The photon energy decreases in each process. The gamma-ray energy suffers thereby a progressive degradation.

The average fractional energy loss in a Compton process decreases in the course of degradation, as shown in Table 3 (*4*). Therefore the gamma photons tend to accumulate in the lower portion of the spectrum, down to the energy range where outright photoelectric absorption becomes predominant (*6*).

Polarization effect. Gamma-ray sources usually generate unpolarized radiation, but the radiation becomes partially polarized in the course of repeated scattering. As a result, any three successive paths of a photon, separated by scattering processes, have a slight tendency to be coplanar. This effect tends to increase the over-all penetration, but by a few per cent at most (*18*).

Complete Problem Formulation

Given a distribution of gamma-ray sources within a material, the general problem of penetration consists of determining the intensity and spectrum of the gammas (primaries and secondaries) which flow in each direction at each point of the medium.

It is adequate to solve the problem separately for sources of monoenergetic gammas of different energies because any source may be regarded as the superposition of monoenergetic sources whose gammas penetrate independently.

Penetration of the primaries. Despite the large accumulation of secondary gammas, the exponential attenuation of the primaries (as observed under "narrow-beam" conditions) usually constitutes the single most important factor affecting the gamma-ray penetration, especially since the primaries usually have a lower μ than do any of their secondaries. This is not true for high-Z materials and primary energies above a few Mev (*6*).

At any point of a medium, the flux of the primary gammas alone can be easily calculated since the primaries penetrate according to the simple "narrow-beam" exponential law (Fig. 2). For a point at a distance x from a gamma-ray source, the product μx in the exponent of $e^{-\mu x}$ in Eq. 2‡ (with the value of μ corresponding to the medium and the source energy under consideration) represents the depth of penetration expressed in "*relaxation lengths*." This number serves as an initial, crude, index of the attenuation of the gammas from the source to the point.

Build-up factor. Since the main problem arises from the accumulation of secondaries, it is often convenient to focus on the ratio of the total amount of gammas at any one point to the amount of primaries only.

For any specific instrument of gamma-ray detection and measurement, at a given location, one may consider its actual response due to all gammas and its ideal response due to the primaries only. The *ratio* of these two responses is the "build-up factor" pertaining to the given instrument and to its location (see Fig. 6). The results of gamma-ray attenuation studies are often expressed as build-up factors.

Simplified Problems

Much understanding and useful information on gamma-ray attenuation is gained from the study of problems schematized so as to involve a reduced number of variables.

Energy degradation only. If a source is distributed uniformly throughout a medium, the secondaries are also distributed uniformly and the only question concerns the accumulation of secondaries of various energies. The same problem arises if one inquires about the spectrum of secondaries

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* Figures 1 and 2 and Tables 1–5 were published with Part I of this article, Aug. '53, p. 8.

† An estimate of this effect, valid for rather thin absorbers and moderate beam apertures has been given, although incorrectly, by Tarrant; see, for example, Davisson and Evans, p. 83 (*16*).

This remark refers mainly to the *number* of photons scattered toward the detector or away from its direction, rather than to the energy retained by these photons after scattering.

‡ Equations 1–6 appeared in Part I.

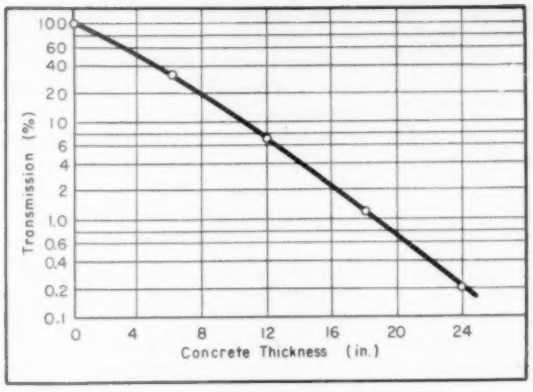

FIG. 5. Broad-beam attenuation curve for Co-60 gammas (17)

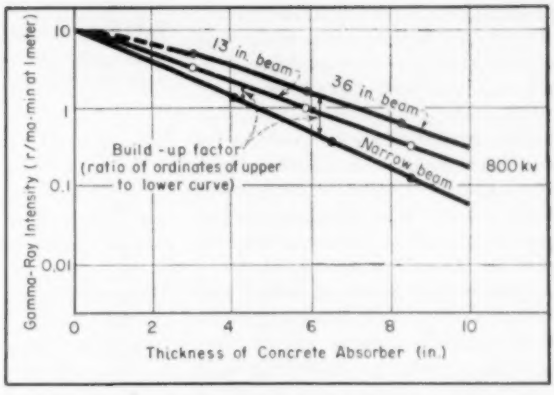

FIG. 6. Build-up of secondary X-rays under broad-beam conditions (19)

integrated over the whole medium, without reference to the source position.

The solution of this problem is straightforward. The spectrum of secondaries is cut off on the low energy side, where the probability of the photoelectric effect rises sharply, and peaks above the cut-off, except for high-Z materials.

The number, $N(E)$, of photons of energy E, is determined by the number of all photons $N(E')$ with energies E' higher than E up to the source energy E_0, multiplied by the probability $p(E,E')$ that the next interaction process changes the energy from E' to E

$$N(E) = \int_E^{E_0} p(E,E')N(E')dE' \quad (7)$$

The number of photons of energy E_0 is given by the source strength; thereafter the equation can be solved stepwise by carrying out the integration to lower and lower values of E. This procedure lends itself well to automatic computer operation.

For exploratory numerical solutions, see Karr and Lamkin (*20*). Extensive calculations have also been made, incidental to more complex problems (see *Available Results of Calculations*).

Degradation and deflection. Photons tend to lose track of their initial direction as a result of successive scattering processes. One may inquire about the distribution-in-direction of the gammas degraded to a certain energy, regardless of their position with respect to the source. Certain obliquity parameters of the distribution-in-direction (such as the mean obliquity of penetration) remain independent of one another in the course of successive scattering processes. Their determination reduces to a number of separate problems equivalent to that of energy degradation only.

If the number of photons of energy E traveling at an angle ϑ with respect to the initial direction is $N(E,\vartheta)$, the "obliquity parameters" are the values of the Legendre polynomials, $P_l(\cos\vartheta)$, integrated over the distribution $N(E,\vartheta)$

$$N_l(E) = \int_0^{\pi} P_l(\cos\vartheta)\, N(E,\vartheta)\, 2\pi \sin\vartheta\, d\vartheta$$

These parameters obey the equations

$$N_l(E) = \int_E^{E_0} p(E,E')P_l\left(1 - \frac{mc^2}{E} + \frac{mc^2}{E'}\right) N_l(E')dE' \quad (8)$$

where p is the same as in Eq. 1. Since $P_0 = 1$, N_0 is the $N(E)$ of Eq. 7 and Eq. 8 reduces to Eq. 7 for $l = 0$; since $P_1 = \cos\vartheta$, N_1 is essentially the mean obliquity, $<\cos\vartheta>$.

For exploratory numerical solutions, see Spencer and Jenkins (*21*). Extensive calculations have also been made, incidental to more complex problems (see *Principles of the Polynomial Method* and *Available Results of Calculations*).

Schematic geometries. Gamma-ray sources distributed in space with particular symmetries lead to distributions of secondaries with corresponding symmetries. Often the gamma distribution depends on a single space coordinate, the distance from the source. (The same simplification can be attained, regardless of source symmetry, by inquiring only about the gamma-ray distribution along one space coordinate, integrated over the remaining coordinates.)

A source distributed uniformly over a plane yields a gamma-ray distribution uniform over any plane parallel to the source plane, which depends only on the distance from the source. Further simplification (without further elimination of variables) arises when the source radiation flows either perpendicularly to the source plane ("plane collimated source" or "plane monodirectional source") or evenly in all directions ("plane isotropic source").

A source concentrated at one point, which radiates evenly in all directions, yields a gamma-ray distribution uniform over every spherical surface centered in the source, and dependent only on the distance from the source.

A source concentrated at one point, and which radiates in a single direction, has only a cylindrical symmetry, which is preserved in the distribution of secondaries. The gamma-ray flux depends on two position coordinates (axial and radial distances). Any source can be regarded as an aggregate of point collimated sources.

Deep Penetration

The study of extremely deep gamma-ray penetrations (*13*) serves (a) to treat unusually severe shielding problems, and (b) to increase confidence in methods of calculation whose reliability tends to decrease as the depth of penetration increases. Deep-penetration studies have led to the establishment of certain mathematical laws and to the development of workable methods of calculation. Most practical problems can be handled by methods suited for moderate penetration.

The most penetrating spectral component. Usually the primary gammas are more penetrating than any of their

secondaries. However, if the energy, E, of the primaries exceeds the energy, E_m, at which the "narrow-beam" absorption coefficient attains its minimum value, secondaries degraded to the energy E_m constitute the most penetrating component of the whole spectrum in the medium and play the leading part in determining the deepest penetration. The value of E_m for various materials is given in Table 6.

Limited equilibrium of softer secondaries. At great depths of penetration, secondaries of energy substantially lower than that of the most penetrating component tend to attain a steady state, namely, to become distributed in energy and in direction in a manner which no longer varies with depth and which is essentially the same as that considered in *Degradation and Deflection*.

Critical spectral range. The dynamics of deep penetration is governed by an ever increasing accumulation of secondaries with energies just below that of the most penetrating component, and which are barely less penetrating than it. The spectral range which is critical in this respect narrows progressively in the course of penetration, whereas the spectral range in a steady state spreads to higher energies.

The accumulation of secondaries follows a different trend depending on whether the most penetrating component has the energy E_m or is the primary itself, i.e., on whether or not the absorption coefficient μ has a minimum in the critical range.

TABLE 6—Energy at Which Narrow-Beam Absorption Coefficients Attain Minimum Values, E_m

Element	E_m (*Mev*)	*Element*	E_m (*Mev*)
$_4$Be	94	$_{20}$Ca	13
$_5$B	70	$_{26}$Fe	9
$_6$C	56	$_{30}$Zn	7.6
$_7$N	46	$_{40}$Zr	5.4
$_8$O	39	$_{48}$Cd	4.4
$_9$F	33	$_{56}$Ba	3.9
$_{10}$Ne	29	$_{74}$W	3.5
$_{13}$Al	21	$_{82}$Pb	3.4
		$_{92}$U	3.3

Since the lower-energy secondaries in a steady state include more and more of the spectrum as the penetration progresses, and thus carry nearly the whole energy flux, the main characteristic of deep penetration is the variation of the intensity level of these secondaries as a function of depth. However, this variation is controlled by the secondaries in the critical range.

Trend of penetration for source energies below the "minimum" E_m. The following applies only to plane collimated, plane isotropic, and point isotropic sources (or combinations thereof); also in principle, but hardly in practice, it applies to any plane source (see ref. *13*, sections 2f and 8).

The intensity of the gamma-ray flux *at great depths*, for source energies below E_m, follows the trend

$$e^{-\mu_0 x} x^K \qquad (9)$$

where x is the distance from the source, μ_0 is the absorption coefficient of the primary gammas in the medium under consideration (expressed in units reciprocal to those of x), and K is a constant. For a plane collimated source, x^K represents the variation of the "build-up" factors.

Notice that x^K is merely *proportional* to the "build-up" factor but is not numerically equal to it. The constant of proportionality depends also on the properties of the detector and therefore cannot be calculated once and for all. The results of calculations discussed later (see Table 9) and of an experiment show that Eq. 9 holds adequately, in some cases at least, for depths upwards of 10–15 relaxation lengths. Incidentally, inspection of Table 9 disproves the frequent notion that the build-up factor always varies linearly with x at low depths.

The constant K for a plane collimated source is given in Table 7. The tabulated value of K must be reduced by 1 for a plane isotropic source and by 2 (inverse-square distance effect) for a point isotropic source.

Trend of penetration for source energies above the "minimum" E_m. The following information applies to all plane sources and to point isotropic sources (or combinations thereof).

The intensity of the gamma-ray flux at great depths, for source energies above E_m, follows the trend

$$x^{-\frac{1}{2}} \exp\left[-\mu_m x + H(\mu_m x)^{\frac{1}{2}}\right] \qquad (10)$$

for plane sources, and

$$x^{-1\frac{1}{2}} \exp\left[-\mu_m x + H(\mu_m x)^{\frac{1}{2}}\right] \qquad (11)$$

for point isotropic sources, where x is the distance from the source, μ_m is the minimum value of the absorption coefficient in the medium under consideration, i.e., the value of μ for gammas of energy E_m (expressed in units reciprocal to those of x), and H is a constant.

The constant H depends on the probabilities of interaction processes for gammas of energies near E_m. (See remarks on x^K following Eq. 9. Equations 10 and 11 become effective at greater depths than does Eq. 9.) Values of μ_m and H for certain materials are given in Table 8.

Semi-asymptotic calculations. A method for the detailed numerical calculation of gamma-ray fluxes from plane sources or point isotropic sources

TABLE 7—Exponent K of Build-Up Factor for Plane Collimated Source as a Function of Source Energy

Source energy (*Mev*)	H_2O	*Al*	*Fe*	*Sn*	*Pb*	*U*
10	0.881	1.23				
8	0.900	1.19	6.10			
6	0.920	1.14	2.60			
4	0.980	1.08	1.56	4.39		
3	1.04	1.15	1.36	2.60	4.85	6.45
2	1.17	1.22	1.30	1.54	1.07	0.880
1	1.52	1.52	1.61	1.25	0.680	0.550
0.8	1.64	1.64	1.70	1.25	0.579	0.450
0.6	1.85	1.85	1.78	1.09	0.430	0.340
0.4	2.26	2.22	1.90	0.780	0.260	0.196
0.3	2.64	2.61	1.75	0.530	0.154	0.120
0.2	3.32	2.78	1.28	0.267	0.0725	0.0550
0.15	3.98	2.55	0.840	0.136	0.038	0.027

which makes use of the mathematical laws and in which the effort required does not increase rapidly with increasing depth of penetration, has been developed through the pilot stage. Results are available for plane collimated sources of 10.2 Mev in Pb and of 5.1 Mev in Fe (*22*).

Moderate Penetration

Much of the detailed information available on gamma-ray penetration derives from calculations which are based, directly or indirectly, on the "polynomial method" (*14*). The labor required by this method is roughly constant up to penetration depths of the order of 10–15 "relaxation lengths" and thereafter increases roughly in proportion to the cube of the penetration, which makes the method unsuitable for extreme depths. Some of the calculations have been checked by experiments, very satisfactorily (*23–25*).

TABLE 8—Values of H and μ_m

Material	μ_m^* (cm^2/gm)	H
H_2O	0.0167	2.0
Al	0.0216	2.1
Fe	0.0300	2.8
Sn	0.0351	2.6
W	0.0391	2.5
Pb	0.0410	2.3
U	0.0425	2.1

* Values of μ_m without Rayleigh scattering, as in Table 1, were used in all calculations of broad-beam attenuation.

The following paragraphs provide some information on the method, which is intended as background for the flexible utilization of its results.

An alternate method (successive calculation of the distributions of photons that have been scattered 1,2,3 . . . times) has received considerable application (*26, 27*), especially to Pb, a high-Z material in which the sequence of Compton processes ends early owing to high photoelectric absorption.

Principles of the polynomial method. Great savings of labor, as well as additional insight, result if the gamma-ray distribution in a medium can be characterized by a few parameters only, which in turn can be calculated directly. (This should be possible since the relevant features of any physical phenomenon are seldom very numerous.) To this end, one may seek an analytical expression for the gamma-ray distribution which contains *in principle* an infinity of parameters (sufficient to describe the distribution in infinite detail) but such that *in practice* the values of all but a few parameters have a negligible influence on the distribution in the range of interest and may be safely disregarded.

At a distance of $\mu_0 x$ "relaxation lengths" from a plane source or point isotropic source, the flux, $N(x,E,\vartheta)$, of photons of energy E traveling at an angle ϑ with respect to the direction of the source has been usually represented as a sum of terms of the following type

$$N(x,E,\vartheta) = e^{-\mu_0 x} \sum_{nl} N_{nl}(E) L_n(\mu_0 x) P_l(\cos\vartheta) \quad (12)$$

Here $e^{-\mu_0 x}$ represents the exponential attenuation of the primaries, $L_n(\mu_0 x)$ is a polynomial of the Laguerre (or related) type, $P_l(\cos\vartheta)$ is a Legendre polynomial, and the $N_{nl}(E)$ are the coefficients to be calculated from theory (see below).

The gamma-ray flux at x, irrespective of direction,* is represented by the terms with $l = 0$ only, i.e.

$$[e^{-\mu_0 x} \sum_{n} N_{n0}(E) L_n(\mu_0 x)]$$

because the $P_l(\cos\vartheta)$ for $l \neq 0$ have average value zero. Calculation of the coefficients with $n = 0,1,2,3$ only, setting those with $n > 3$ equal to zero, may yield an adequate approximation for $\mu_0 x$ as large as 10, or even 15,† in the sense that the terms with $n > 3$ would yield no substantial correction in this range. Any other analytical expression which can be fitted by a calculation equivalent to the calculation of the N_{nl} would be equally acceptable, provided it converges adequately.

The parameter N_{00} is essentially the same as the number of photons, $N(E)$, of Eq. 7, and the parameters N_{0l} are essentially the same as the "obliquity parameters," N_l, of Eq. 8; they depend on the number of photons of certain energies and directions, *irrespective* of their distance from the source.

The parameters $N_{nl}(E)$ depend on the same numbers of photons, but *weighted* in proportion to certain functions of their distance from the source (polynomials of grade n). Each N_{nl} is determined by an equation similar to Eq. 8, but with a correction which requires previous knowledge of parameters with lower values of n. Thus the N_{nl} can be calculated in succession for higher and higher values of n.

Available results of calculations. The raw results of calculations have the form of "weighted obliquity parameters," as indicated above, calculated separately for various materials, source geometries, and source energies, and tabulated for a series of secondary photon energies. These data usually get processed and published in part, in the form of answers to specific questions, such as plots of the build-up factor for a specific instrument vs distance from the source. However, processed and published data may not answer just the type of question required for a specific application (e.g., they may not give the build-up factor for a desired type of instrument, or they may fail to give indications regarding the distribution-in-direction). In this event, the desired application may be achieved by procuring the original raw data (see below) and by reprocessing them according to the particular need.

Pilot calculations have been made in sizable numbers (*18, 25, 28–31*) and, in part, checked by experiments (*23–25*). These results serve primarily, at present, to provide a quantitative illustration of certain specific features of the gamma-ray flux.

NDA-NBS program. A comprehensive program of calculations by the polynomial method is being carried out by Nuclear Development Associates, in conjunction with the Bureau of Standards (*32*). The aim of the program is directed at producing answers on gamma-ray penetration for materials, source geometries, and initial energies of interest in shielding. Accordingly, the initial energies chosen generally cover the range from 0.5 to 10 Mev.

The materials involved extend over the complete periodic table, including: pure Compton scatterer, H_2O, Al, Fe, Sn, W, Pb, and U. For almost all of the materials and source energies, com-

* Notice the difference between the total flux through a point irrespective of direction and the net transport through a plane perpendicular to the source direction.

† The reason for the success of the representation in Eq. 12 is discussed by Spencer and Fano (*14*).

TABLE 9—Dose Build-up Factor for Point Isotropic Source

E_0 (Mev)	$\mu_0 r$ 1	2	4	7	10	15
WATER						
0.256	3.09	7.14	23.0	72.9	166	455
0.5	2.52	5.14	14.3	38.8	77.6	178
1	2.08	3.50	7.21	14.6	24.0	44.7
2	1.83	2.77	4.88	8.46	12.4	19.5
3	1.69	2.42	3.91	6.23	8.63	12.8
4	1.58	2.17	3.34	5.12	6.94	9.97
6	1.46	1.91	2.80	4.08	5.33	7.34
8	1.39	1.77	2.49	3.51	4.50	6.05
10	1.32	1.63	2.22	3.04	3.82	5.07
LEAD						
0.5		1.42	1.69	2.00	2.27	2.65
1		1.69	2.26	3.02	3.74	4.81
2		1.76	2.51	3.66	4.84	6.86
3		1.68	2.43	3.75	5.30	8.44
4		1.56	2.25	3.61	5.44	9.80
5.11		1.46	2.08	3.44	5.55	11.74
6		1.40	1.97	3.34	5.69	13.80
8		1.30	1.74	2.89	5.07	14.05
10		1.23	1.58	2.52	4.34	12.54

E_0 (Mev)	$\mu_0 r$ 2	4	7	10	15	20
ALUMINUM						
0.5	4.24	9.47	21.5	38.9	80.8	141
1	3.31	6.57	13.1	21.2	37.9	58.5
2	2.61	4.62	8.05	11.9	18.7	26.3
3	2.32	3.78	6.15	8.65	13.0	17.7
4	2.08	3.22	5.01	6.88	10.1	13.4
6	1.85	2.70	4.06	5.49	7.96	10.4
8	1.68	2.37	3.45	4.58	6.56	8.52
10	1.55	2.12	3.01	3.96	5.63	7.32
IRON						
0.5	3.09	5.98	11.73	19.23	35.42	55.6
1	2.88	5.39	10.21	16.18	28.31	42.7
2	2.38	4.08	6.99	10.47	16.83	24.0
3	2.12	3.44	5.74	8.35	13.25	18.8
4	1.94	3.03	4.91	7.11	11.23	16.0
6	1.72	2.58	4.14	6.02	9.89	14.7
8	1.56	2.23	3.49	5.07	8.50	13.0
10	1.42	1.95	2.98	4.35	7.54	12.4

putations have been made for point isotropic sources, and in most cases also for plane monodirectional source geometry.

In addition, for Compton scatterer, iron, and lead (the most important class of materials in practice) calculations have also been made for infinite plane sources in which the distribution of the source photons in the angle θ from the normal to the plane is given by the Legendre polynomials, $P_n(\cos\theta)$, $n = 1,2,3$. Since the P_0 case (plane isotropic) is directly related to the point isotropic solution, the results cover the first four Legendre polynomials, which, it is hoped, will enable one to approximate the answer for any arbitrary plane source, symmetric about the normal, which does not vary too rapidly with θ.

The range of penetrations which these calculations are designed to cover is from 1 to 20 "relaxation lengths" from the source. The number of moments needed for such penetrations, and the number of cases considered, is so extensive as to preclude hand computations. Instead, the Bureau of Standards automatic computer, SEAC, has been used in all problems.

Certain simplifications in the nature of the gamma-ray interaction have been made which greatly reduce the complexity of the calculations without significantly affecting the accuracy of the results. Only three processes have been considered. Two of these, photoelectric effect and pair production, have been assumed completely absorptive, thus neglecting such secondary effects as fluorescence, bremsstrahlung, and annihilation radiation. The third process, incoherent Compton scattering, is the only scattering treated. For the energies and materials discussed, coherent scattering is at such small angles that its effect may be disregarded, and has therefore been omitted from both the total absorption coefficient and the scattering kernel. Polarization effects in the incoherent scattering have also been neglected.

TABLE 10—Energy Absorption Coefficient for Air

E (Mev)	μ_A (cm²/gm)	E (Mev)	μ_A (cm²/gm)
0.03	0.139	0.6	0.0292
0.04	0.0616	0.8	0.0290
0.05	0.0376	1	0.0276
0.06	0.0286	1.5	0.0254
0.08	0.0236	2	0.0236
0.1	0.0232	3	0.0210
0.15	0.0250	4	0.0193
0.2	0.0268	5	0.0182
0.3	0.0288	6	0.0173
0.4	0.0294	8	0.0162
0.5	0.0294	10	0.0155

It is difficult to state the expected accuracy of the results, as it varies with the number of moments calculated, the type of material, the penetration, and the energy region of the scattered spectrum being considered. In general, the error in integrated quantities, such as build-up factors, will have less effect on the final calculated intensity than will the normal uncertainties in the value of the absorption coefficient.

It is expected that full details of the calculation will be published in 1953 as an Atomic Energy Commission report. Complete tables of build-up factors and differential spectra will be included in the report, along with illustrative examples of angular distributions. These results will not exhaust the calculations which can be made from the raw output of the machine, however. To make these more generally available, it is therefore intended to place annotated microfilm copies of the SEAC output at each of the AEC deposit libraries.

Tables of build-up factors. To illustrate the type of results obtained from the NDA-NBS program, Table 9 presents the calculated dose build-up factors with a point isotropic source in an infinite medium composed of H_2O, Al, Fe, and Pb, respectively. The designation "dose" indicates that the gamma-ray flux is to be measured

in terms of roentgens, i.e., with the energy spectrum weighted in proportion to the energy absorption coefficient of air. Table 10 lists the values used here in computing the build-up factors given in the tables.

The accuracy of the results for Pb and Fe is estimated roughly at 5% except at the greatest penetration, where the errors may be as large as 15%. The low-energy portion of the spectrum (which is the most difficult to calculate) contributes disproportionately to the dose build-up factor for water and aluminum. Hence the limit of error for these materials is undoubtedly greater, probably being around 10% for medium penetrations, rising to 25–30% for the deepest penetration.

Sources of Experimental Data

Considerable amounts of experimental data have been taken regarding various phases of gamma-ray penetration. However, most of the effort was directed to the solution of specific problems and therefore had a limited usefulness for the purpose of general penetration study. Other recent experiments had more general aims but represent, thus far, only initial stabs. Some pertinent references will be given here, grouped according to their line of endeavor.

Data on gamma-ray distribution in phantoms. Radiologists need estimates of the "dose" received by various portions of a body which is exposed to a radiation beam of given area and given characteristics. Very many experiments were made, mostly using mock-ups of human bodies ("phantoms"), with X-ray beams up to the million-volt range, some also with betatrons. There is data available for both the low-energy range (*33–35*) and the high-energy range (*36, 37*).

Radiological shielding data. The design of safe radiological installations has stimulated much work (*19, 38–41*). Until recent times, radiological shielding studies constituted nearly the sole source of information on high-energy gamma penetration.

Other studies. A systematic analysis of the backscattering of a collimated beam of Co^{60} gammas by the surface of a semi-infinite medium of various materials has been conducted (*42*).

Studies of the influence of a nearby wall upon the response of a detector have also been made (*43, 44*). For example, Kennedy *et al.* found that when an ionization chamber was brought near a concrete barrier, remaining at a fixed distance from a Co^{60} source, its reading was subject to increase of the order of 10%.

Data on the radiation scattered sidewise by a phantom exposed to an X-ray beam are given in the radiological literature (*38, 45, 46*).

Little experimental information seems to be available on radiation transmitted through a barrier. Spectral analysis by scintillation counters is in progress (*47*).

Measurements have been made of the transition effect at the surface of a water tank as the source and/or the detector pass from air to water (*48*).

A study on the effect of voids in a water tank is reported in the classified literature.

* * *

The sections on NDA-NBS Program *and* Tables of Build-up Factors *were contributed by H. Goldstein of Nuclear Development Associates. Table 6 was prepared by G. R. White. Table 7 was prepared by L. V. Spencer and John Doggett. Table 8 was prepared by L. V. Spencer. Tables 9 and 10 were prepared by Nuclear Development Associates.*

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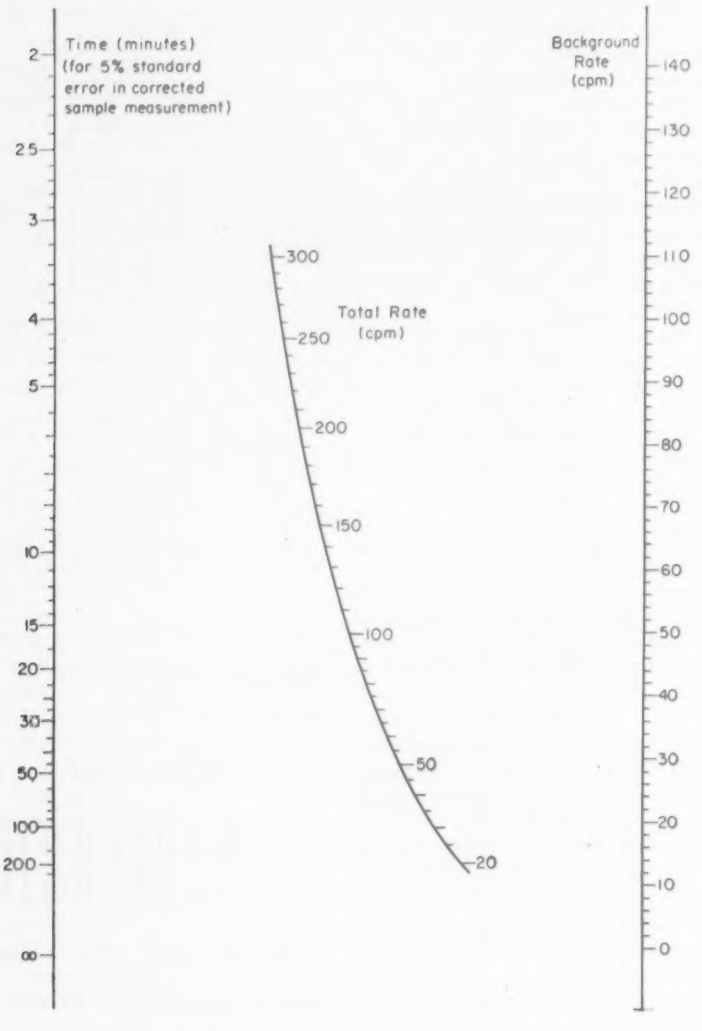

Nomogram for Counting Time

By WILLIAM C. DAVIDON
Director of Research
Nuclear Instrument and Chemical Corp.
Chicago, Illinois

Measurements are frequently made of a group of samples whose activities are comparable with background. Considered here is the case in which the background is relatively constant and the number of samples large.

To maintain a desired accuracy for the net sample measurements with a minimum total expenditure of time, the background should first be measured to an accuracy considerably greater than that desired for the results. Then each sample should be counted for a period of time sufficient to obtain the desired final accuracy. The purpose of this nomogram is to provide a simple method for determining this time.

Use of Nomogram

The method suggested for using this nomogram is as follows:

1. Determine the accuracy required for the results of the measurements. A standard error of 5%, corresponding to 3.4% probable error, has been chosen for the scales of the nomogram, but a simple conversion described later permits its use for other accuracies.

2. Measure background to an accuracy considerably greater than that desired in the results. How much greater depends upon how close to background the samples will run; for most purposes, an accuracy in background measurement of two to three times the final accuracy is ample.

3. When counting each sample, note the total counts after the first minute.

4. Using the background rate from **2**, and the approximate total counting rate given by **3**, place a straight-edge on the nomogram to determine how long to continue the counting.

5. If the accuracy desired is different than 5% standard error, the time to be used is determined by the fact that the time is inversely proportional to the square of the accuracy desired. For example, if 1% standard error is desired, the times indicated on the nomogram should be multiplied by 25.

Construction of Nomogram

The nomogram is constructed from the equation

$$(n/t)^{1/2}[1/(n-b)] = a$$

where a is the standard error in the net sample measurement, expressed as a fraction, b is the background rate, n is the total counting rate, t is the time for the measurement, and $n - b$ is the corrected sample rate.

This equation can be expressed as

$$\begin{Vmatrix} 1 & b & 1 \\ 0 & \dfrac{c}{at^{1/2}} & 1 \\ \dfrac{c}{c+n^{1/2}} & \dfrac{cn}{c+n^{1/2}} & 1 \end{Vmatrix} = 0$$

where c is an arbitrary constant. For each scale, b, n, and t, the expression in the first column gives the x coordinates of each point; while the second column gives the corresponding y coordinates.

For the limiting condition of no background, the time required is such that the total number of counts, nt, is equal to 400. At the other extreme, when the total rate is the same as the background rate, $n = b$, the time required is infinite.

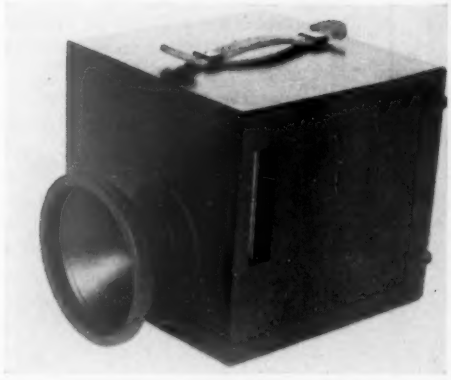

FIG. 1. Developmental model of air sampler. Filter fits in collector at left

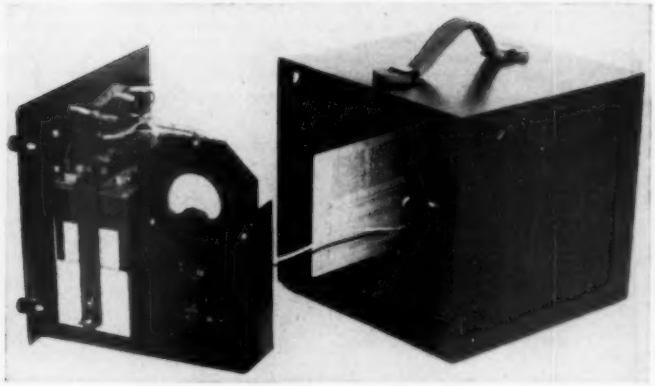

FIG. 2. Disassembled developmental model. Fan motor is in case, batteries, charging ammeter and potentiometer at left

Portable Air Sampler for Collection of Radioactive Dust

By BERNARD REICH
Signal Corps Engineering Laboratories
Fort Monmouth, New Jersey

Airborne radioactive particulate matter constitutes a potential health hazard to personnel entering a contaminated area. To assess the hazard, a dust sample collector and radioactivity detector are required. In areas where no commercial or field generated power is available, this equipment has to be self powered. But its weight must be limited to allow convenient carrying.

A portable air sampling unit has been designed to meet these requirements. Air is drawn through a filter-paper disk by a battery-powered blower. The dust activity collected on the filter is measured with radiac set AN/PDR-34, an ionization chamber type of survey instrument with windows for alpha and beta determinations. With appropriate calibration, type of radiation can also be determined.

Other survey instruments could also be used for measurement, but the size of the filter-paper disk was chosen for use with the AN/PDR-34.

Design Considerations

Analysis of dust collection methods indicated that filtration was the simplest and most suitable method for field air sampling. Filters have efficiencies of reclamation as high as 99% for particle sizes as small as 0.5 μ. Particles differing in size do not constitute a personnel hazard to the same degree, but since all sizes collected by the filter contribute to the measured activity, assessment of the hazard will always be on the safe side.

With filter size determined by existing detectors, blower characteristics were chosen to provide a sampling rate that simulated personnel breathing while walking at 2 to 4 miles per hour.

Air Sampler Models

A laboratory and a developmental model of the air sampler have been built. Their characteristics are compared in the table on this page. The developmental model, constructed by Mine Safety Appliances Co., Pittsburgh, Pa., is shown in Figs. 1 and 2, and its characteristic curve is shown in Fig. 3. The increased weight of the developmental model is caused by a change in batteries to increase operating time.

Both models have provisions for recharging the wet-cell batteries used, and an ammeter and potentiometer are provided for adjustment of charging.

* * *

The developmental model air sampler, MX1191( )/TDQ-1, was constructed under contract DA36-039 SC-15340.

CHARACTERISTICS of Air Samplers

	Laboratory model	*Developmental model*
Dimensions (sampling head removed)(in.)	$5\frac{1}{2} \times 10 \times 8$	$8\frac{3}{4} \times 9 \times 8\frac{1}{4}$
Weight (lb)	10	15
Power supply	Four 6-volt batteries (BB-214U)*	Three 2-volt batteries (BB-240U)*
Blower	24-volt blower with centrifugal type squirrel cage wheel (MX215/APG)*	6-volt blower (see Fig. 3 for characteristics)
Intake assembly	Conical shaped aluminum housing with provision for clamping $4\frac{1}{8}$-in.-diameter filter paper. Lip size is increased on developmental model.	
Collection measurement	Area meter used on both models. Introduces additional back pressure equal to 1 in. water.	

* Signal Corps model numbers.

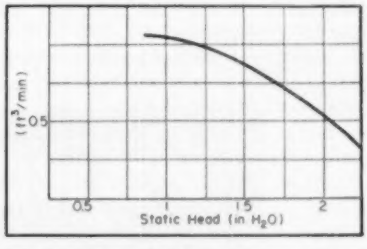

FIG. 3. Characteristic curve of developmental model

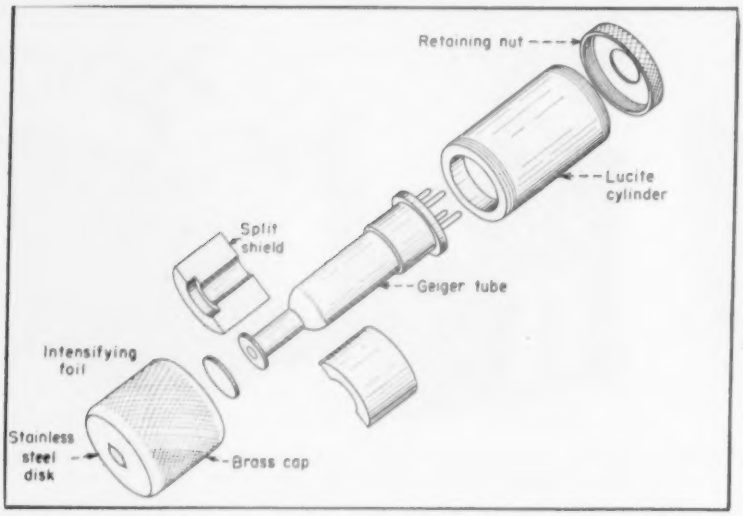

FIG. 1. Exploded view of low-background, small-diameter end-window tube with light-weight shield and intensifying screen

Obtaining Increased γ-Sensitivity in an End-Window Geiger Tube

By FRANK E. HOECKER and PAUL N. WILKINSON
Radioactive Isotopes Research Laboratory
University of Kansas, Lawrence, Kansas

A number of methods have been used to increase the efficiency of Geiger tubes for gamma-ray counting. Most of these involve some form of coated cylinder built into the tube during manufacture. Maximum advantage of the enhanced sensitivity can be taken only by using the tube side-on to the radiation. In certain applications that require use of the tube end-on, this type of construction is a disadvantage because it requires the use of considerably increased lead thickness in the wall shield to avoid an objectionable increase in background. This extra lead shielding can be a serious handicap. Moreover, the end-on use does not permit realization of the full increase in gamma-ray efficiency since the radiation does not enter the tube through the intensifying cylinder.

But there are certain applications in which the use of an end-window tube is essential. An instance of this is the use of such a tube for the survey of the thyroid area in a patient to whom radioiodine has been administered for diagnostic purposes.

The thyroid area is surveyed, by placing the tube in contact with the skin, to outline the thyroid gland and to locate small toxic adenomas. Greater precision of localization can be achieved by means of a lead collimating shield that reduces the aperture to approximately 1 cm in diameter. When this is done, however, the sensitivity of the ordinary* end-window tube to the gamma rays from I^{131} is too low for convenient use. A further disadvantage of the ordinary end-window tube is the weight of the lead shield when the tube is held by hand during the survey procedure. (Loss of flexibility makes mechanical support impracticable.)

A partial solution of the problem may be achieved by utilizing a removable lead intensifying screen in contact with the thin end window of the tube. When this is done, the secondary electrons resulting from gamma-ray absorption in the lead foil will penetrate the end window. By thus taking advantage of the higher efficiency of the tube for beta particles, the over-all sensitivity to gamma rays is increased by a factor of approximately 1.9, depending on end-window thickness.

A complete solution, however, to both the shield weight problem and the sensitivity problem has been found by a combination of the intensifying lead foil with a rather unusual design of end-window tube.† This tube, as shown in Fig. 1, has a diameter of about ¾ in. for about two-thirds of its length at the base end and a diameter of about ⅜ in. for the remaining one-third of its length, terminating in an end window about ¼ in. in diameter. This results in a tube much smaller than the usual end-window tube.

This tube has as one outstanding advantage a very small sensitive volume of about ½ cm^3 located very close to the thin end window. This permits a decided reduction in the weight of the lead shield since it need surround only about 1 in. of the small-diameter portion of the tube. Since the terminal end of the tube is flared to facilitate attachment of the end window, the lead shield must be split to permit its being fitted to the tube. This splitting of the lead shield necessitates the use of a cylindrical tube and shield support.

The complete unit, shown in Fig. 1, weighs 1 lb. A Lucite cylinder (1-in. internal diameter, ¼-in. walls) is threaded at both ends. The Geiger tube is rigidly supported in this cylinder by clamping the flange at the bottom of the tube between the upper end of the cylinder and a threaded brass ring. The split lead shield is independently supported around the lower end of the tube by a short brass cylinder that screws to the lower end of the Lucite cylinder. The lead shield must be held firmly between the end of the Lucite cylinder and the stainless-steel disk that closes the end of the brass cylinder.

The lead foil intensifying screen is placed in contact with the end window of the tube and crimped around the flanged end to hold it in position before the lower brass cylinder is put in position.

The thickness of lead foil is rather critical, being determined by the energy of the gamma radiation and the thickness of the end window. It should be possible to calculate the optiumm thickness of the intensifying

* Tubes TGC-1 or 2 (Tracerlab, Inc., Boston, Mass.) or Model 20 (Radiation Counter Laboratories, Chicago, Ill.).

† Mark 1, Model 105 (Radiation Counter Laboratories, Chicago, Ill.).

Operator transfers evacuated retort from heating to cooling station of Stokes Vacuum Annealing Furnace, designed and built for the processing, annealing and other heat treatment of titanium, zirconium, hafnium, copper and other metals.

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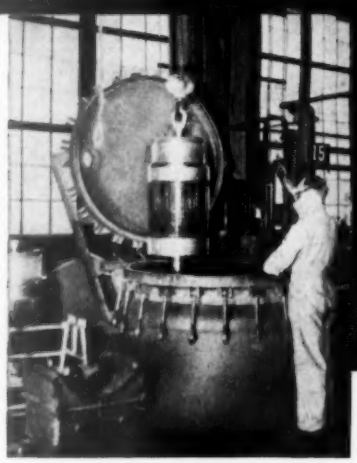

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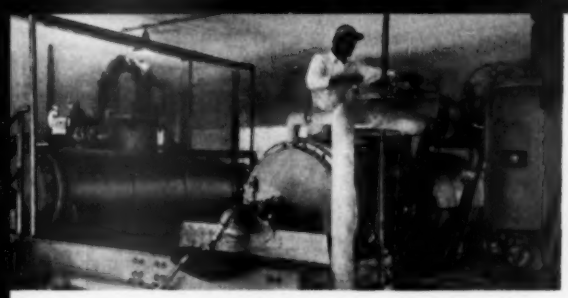

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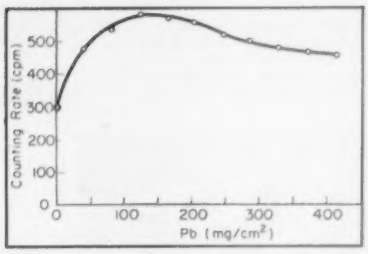

FIG. 2. Dependence on lead-foil thickness of increase in sensitivity of tube for I^{131} gamma rays

foil by taking these factors into consideration. But it is much more expedient to determine this thickness experimentally by measuring the response of the tube for different lead-foil thicknesses. A graph of data for one particular tube (Fig. 2) shows a maximum intensification factor of 1.9 for a foil thickness of 125 mg/cm². This increased sensitivity factor is less than that obtained by use of an internal bismuth wall but may be sufficient to be the deciding factor in consideration of the usability of the tube. In this connection it should be borne in mind that the background of this tube is very low and that the use of the lead-foil intensifier results in an increase in only that very small portion of the background due to gamma rays entering through the end window. The advantage is therefore greater than that indicated by the numerical value of the sensitivity factor.

Estimation of Self-Absorption within a Homogeneous Cylindrical Source

By EDWIN L. FIELD
Tracerlab, Inc.
Boston, Massachusetts

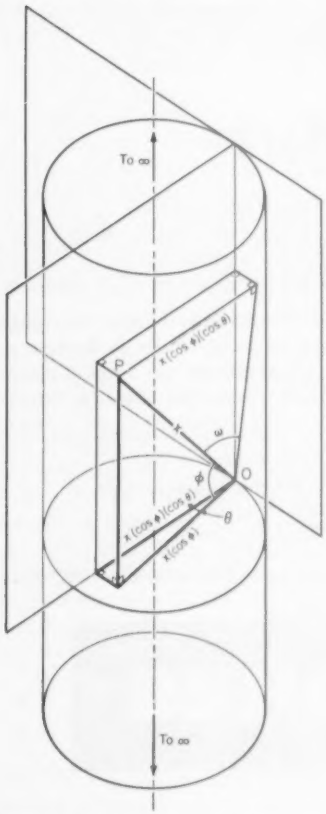

FIG. 1. Spherical coordinate system

The problem of estimating the amount of beta or gamma radiation absorbed within a homogeneous active cylinder is of importance in the consideration of such widely divergent topics as the use of radiation for sterilization of materials, the treatment of cancers by means of radioactive wires or needles, the external monitoring of materials flowing within cylindrical pipes, and the heat-transfer problems associated with cylindrical slugs of very active material.

In arriving at the solution to this problem presented here, the following assumptions are made:

1. The length L of the cylinder is long in comparison with its diameter D. The solution, while strictly valid only for $L/D = \infty$, is applicable as long as $L/D > 2.5$.

2. The absorption of radiation within the cylinder obeys the exponential absorption equation, $I/I_0 = e^{-\mu x}$, where μ is the absorption coefficient of the cylinder material.

Consider Fig. 1, in which O, a point on the surface of the central portion of a long cylinder, is chosen as the center of a system of spherical coordinates.

Since, in this coordinate system, the volume of a differential element at (x,θ,ϕ) is given by

$$dV = (dx)(x\,d\phi)(x\cos\phi\,d\theta) = x^2(\cos\phi)dx\,d\theta\,d\phi \quad (1)$$

the activity in this differential volume is equal to

$$dA = A_0x^2(\cos\phi)dx\,d\theta\,d\phi \quad (2)$$

where A_0 is the specific volumetric activity of the source material.

If the radiation from point P, within the cylinder at (x,θ,ϕ), were unattenuated in passing through the distance x to point O, the intensity of radiation from this element impinging on the surface of the *sphere* passing through O and having its center at P would be equal to

$$[A_0x^2(\cos\phi)dx\,d\theta\,d\phi]/4\pi x^2$$

The intensity of this radiation normal to the *cylinder* at O is equal to this value multiplied by $\sin\omega$, where ω is the angle which OP makes with the cylindrical surface. It can be seen by reference to Fig. 1 that

$$\sin\omega = \frac{x(\cos\phi)(\cos\theta)}{x} = (\cos\phi)(\cos\theta) \quad (3)$$

and thus the intensity of radiation from the cylindrical surface at O caused by the activity at point P, attenuated by a factor of $e^{-\mu x}$, is

$$I_p = \frac{A_0x^2(\cos\phi)\,dx\,d\theta\,d\phi}{4\pi x^2} \times (\cos\phi)(\cos\theta)(e^{-\mu x}) = \frac{A_0}{4\pi}(\cos^2\phi)(\cos\theta)(e^{-\mu x})\,dx\,d\theta\,d\phi \quad (4)$$

To find the total activity escaping per unit area at O, Eq. 4 must be integrated between limits. The expression is meant to apply to radiation from all points *within* the cylinder; therefore, to express the surface of the cylinder as the limit, the equation of the cylindrical surface in the spherical coordinate system set up in Fig. 1 is needed. Inspection of Fig. 2 will show that the equation of all points on the surface of the cylinder is simply

$$x = D\cos\theta/\cos\phi \quad (5)$$

Integrating Eq. 4, using this boundary equation, for one of the axial halves of one of the transverse halves of the cylinder (and multiplying the result by 4, since there are four such symmetrical sections making up the cylinder)

$$I = 4\int_0^{\pi/2}\int_0^{\pi/2}\int_0^{D\cos\theta/\cos\phi}\frac{A_0}{4\pi} \times (\cos^2\phi)(\cos\theta)(e^{-\mu x})dx\,d\theta\,d\phi = \frac{A_0}{\pi}\int_0^{\pi/2}\int_0^{\pi/2}\int_0^{D\cos\theta/\cos\phi} \times (\cos^2\phi)(\cos\theta)(e^{-\mu x})\,dx\,d\theta\,d\phi \quad (6)$$

where I is the total radiation escaping

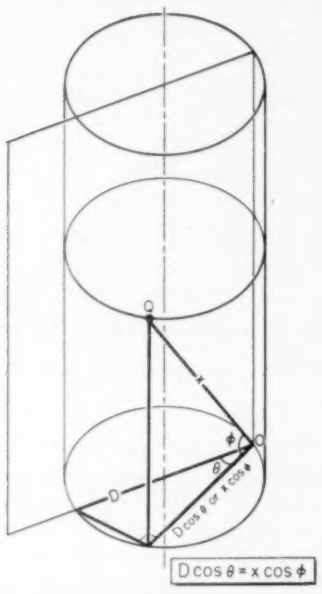

FIG. 2. Cylindrical surface in spherical coordinate system

from the cylinder per unit area at point O.

We now define the "effectiveness factor," f, as the ratio of this intensity to that which would be found if there were no self-absorption within the cylinder. Neglecting end effects (permissible at the central portion of a "long" cylinder) one finds that the radiation escaping per unit area from a "transparent" cylinder would be

$$I_{\text{unattenuated}} = \frac{(\pi D^2/4)(L)(A_0)}{(\pi)(D)(L)} = \frac{A_0 D}{4} \quad (7)$$

This result can also be obtained by analytic integration of Eq. 6 for the special case of $\mu = 0$.

Dividing Eq. 6 by Eq. 7

$$f = \frac{4}{\pi D}\int_0^{\pi/2}\int_0^{\pi/2}\int_0^{D\cos\theta/\cos\phi} \times (\cos^2\phi)(\cos\theta)(e^{-\mu x})dx\,d\theta\,d\phi \quad (8)$$

Integrating this expression with respect to x

$$f = \frac{4}{\pi\mu D}\int_0^{\pi/2}\int_0^{\pi/2} (\cos^2\phi)(\cos\theta) \times (1 - e^{-\mu D\cos\theta/\cos\phi})d\theta\,d\phi \quad (9)$$

This expression was carefully integrated by graphical means with respect to θ and ϕ. The final result is expressed graphically in Fig. 3, in which f is expressed as a function of μD.

The significant features of this plot can be summarized as follows:

1. There is essentially no internal self-absorption for cylinders where

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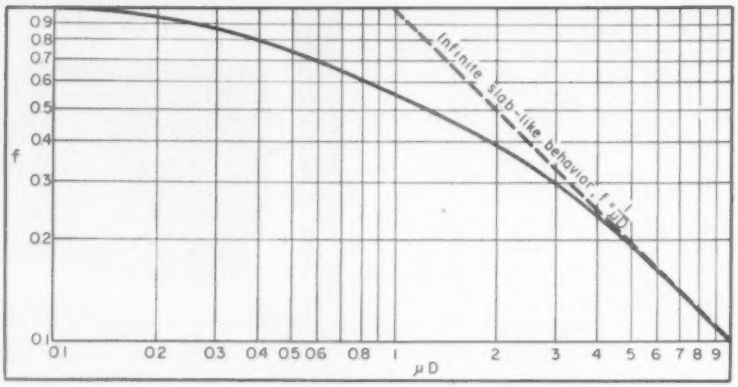

FIG. 3. *f* as a function of μD

$\mu D < 0.14$ (in other words, where $D < 0.2$ half-thickness), since the plot shows $f = 1$ for these cylinders.

2. For cylinders where $\mu D > 6$ (in other words, where $D > 9$ half-thicknesses), f decreases inversely as μD increases. This is because, when $\mu D > 6$, the source surface behaves as if it were that of an infinitely thick slab (for which it can be shown that $I = A_0/4\mu$). Thus, increasing the diameter of an active cylinder above $\mu D = 6$ results in no further increase in surface intensity (per cm²) but does, of course, increase the total radiation escaping per unit length of cylinder, since the total surface area per unit length is proportional to the diameter.

Example of Use

To illustrate the use of the plot, consider the following problem:

A 2-in. pipe is filled with water in which a small amount of a Co^{60} salt is dissolved; how much of the gamma radiation is absorbed within the liquid (i.e., does not get to the inner wall of the pipe)?

If we assume the absorption coefficient for gamma radiation of approximately 1.2 Mev maximum energy to be approximately 0.06 cm^{-1} in water, the μD product would be (0.06)(2.067)(2.54) = 0.315. Reference to Fig. 3 shows that $f = 0.85$ in this case. Therefore, one would expect a "loss" of about 15% of the gamma-radiation energy by absorption within the liquid itself. A similar calculation may be made for the beta radiation.

This method of estimating internal absorption ("self-absorption") in cylindrical sources was developed originally to assist in making estimates of required activity levels for various industrial applications of radioactivity. The accuracy of this rapid method depends upon the validity of the simple mechanism assumed for absorption. The exponential equation used was thought to be a reasonable first approximation, and the result presented in Fig. 3 should be of use to those attacking new problems where experimental data are not available.

Simple Synthesis of Diiodo^{131}-fluorescein

By J. VIGNE and J. FONDARAI

Laboratoire des Isotopes du Centre Anti-Cancereux de Marseille Marseille, France

Boyack and Moore have described a method for synthesis of labeled diiodofluorescein (*1*). We have found (*2, 3*) that this labeled compound can be prepared by stirring mechanically for 20 minutes stochiometric quantities of crystallized basic fluorescein, 0.5% solution in neutral phosphate buffer, and I^{131}, 0.5% solution in chloroform.

After stirring, chloroform is removed and ethylacetate added. The mixture is acidified, and then the labeled diiodofluorescein dissolves in solvent.

Buffer is removed and ethylacetate evaporated. The labeled diiodofluorescein is dissolved in a small quantity of 2% CO_3Na_2 solution.

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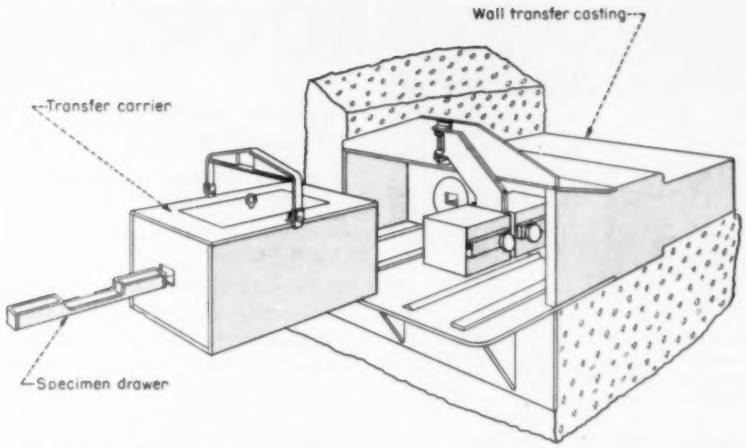
2. J. Fondarai, J. Vigne, *Bull. Soc. Chim. France* **1953**, 23 (1953)
3. J. Vigne, J. Fondarai, *ibid* **1953**, 331 (1953)



WALL TRANSFER UNIT. Transfer carrier holding specimen drawer is placed on ledge; specimen drawer is pushed through tunnel into hot cell. Shielding block can be swung into place to block end of tunnel

Wall Transfer Unit and Transfer Carrier for Hot Cells

By C. W. ANGEL and F. RING, Jr.
Engineering Department, Oak Ridge National Laboratory
Oak Ridge, Tennessee

One of the problems in experiments with radioactive substances is the safe handling of such materials. This article describes a unit designed to transfer solid radioactive specimens safely from a shipping carrier or a canal to the interior of a shielded hot cell. It is especially useful for safely moving radioactive specimens in and out of the cells when they become highly contaminated.

The unit was designed by the Engineering Department for the Solid States Division of ORNL for use in their hot cells. It consists of a double-tunneled steel casting, permanently located in the 3-ft-thick concrete cell wall, and a shielded, single-drawer transfer carrier.

Operation. The Solid States building at ORNL has a deep water pit that can be used for transferring specimens from any standard shipping carrier into the transfer carrier, while the material is under 12 ft of water. The transfer carrier is then lifted by the building crane and positioned on a ledge affixed to the steel wall-transfer casting. Grooved tracks on the carrier and on the ledge insure proper alignment of the specimen drawer in the carrier with either of the two tunnels.

The loaded carrier drawer is pushed through the tunnel opening to the interior of the cell, where the radioactive specimen may be removed by a general-purpose manipulator.

Transfer carrier. As shown in the accompanying figure, 6 in. of lead is used both in front and back of the drawer opening so that the radioactive specimen will be completely encased with a minimum of 6 in. of lead as long as it is within the carrier. The top plug is stepped for radiation protection and is removable to facilitate underwater loading.

Safety interlocks have been designed for the carrier. The bail cannot be lifted for engagement with a crane hook unless the drawer is completely within or completely outside the carrier. Also, the drawer cannot be removed when the bail is in the raised position. This eliminates the possibility of the drawer sliding out while the carrier is being transported by the crane. The crane hook must be removed, and the bail lowered, before the specimen drawer can be pushed out of the carrier.

Wall transfer casting. The wall transfer casting is cast in the cell wall. Its two tunnels lead to the corners of adjacent cells. Radiation streaming is less likely to occur at this location, and the tunnels may be used for intercell transfer in emergencies. Another facility is available for normal transfer from one cell to another.

Each transfer tunnel contains a rolling bed or shelf that supports the carrier drawer as it is pushed from the carrier into the cell with a push rod. The push rod also serves to lock the drawer to the rolling shelf. The inner end of this support shelf contains a 6-in.-long lead plug that serves to shield the tunnel when the specimen drawer and carrier are removed.

Additional radiation protection. In addition to the interior plug in each tunnel, there is a 6-in. cube of lead mounted to the outer wall. This cube can be rotated to block the tunnel opening after the carrier is removed from the wall ledge.

The wall transfer unit is recessed in the cell outer wall to eliminate radiation streaming along the face of the cells when the drawer is being pushed from the carrier.

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• **Internal pipeline camera** for radiographing welds on oil-transporting pipelines positions source automatically. Control mechanism at rear of unit detects low-activity control source placed outside pipe near weld (wrapped with film) to be radiographed, and automatically stops unit in correct position. Radiography source is exposed for preset time; then control starts unit on towards next weld. The unit was developed by L. Shemansky and B. Richards of Isotope Products Ltd., Oakville, Ont., Canada.

• **Electronic flowmeter** developed by H. P. Kalmus of the National Bureau of Standards utilizes phase shift in sound wave transmitted through flowing medium to measure velocity.

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BOOKS

Mesons—A Summary of Experimental Facts

By ALAN M. THORNDIKE (McGraw-Hill Book Co., Inc., New York, 1952, viii + 242 pages, $5.50). Reviewed by R. D. SARD, Department of Physics, Washington University, St. Louis, Mo.

The subtitle of this book has an old-fashioned ring, evoking the time when it was possible to distinguish, at least superficially, between fact and theory. Actually, theoretical assumptions are implicit in the interpretations of even the simplest experiment, and these assumptions do, of course, change with time. In addition, some of the experimental numbers turn out to be incorrect, and the rest inaccurate, so that a better subtitle for a book such as this would be "a summary of experimental results."

As such a summary, the book serves its purpose admirably. It is a conscientious and well organized survey of the experimental research on μ- and π-mesons reported up to early 1952.

With the exception of early papers by Alichanian and his coworkers on "varitrons," Soviet publications are ignored. The author states in a footnote on p. 58, "omission appeared preferable to incomplete discussion and inadequate evaluation." Confronted, like the author, with the difficulty of keeping up with articles in a strange tongue appearing in periodicals whose export to American libraries has been stopped, the reviewer understands this decision. But he cannot approve it. Science is indivisible. Despite all the difficulties, we must try to keep up with Soviet work. As a member of the Brookhaven National Laboratory, the author was in a favored position in this respect, for Brookhaven's "Technical Information Division" maintains a file of translations from the Russian. Since "varitrons" are discussed in the book, it would have been especially appropriate to report the recent papers from Skobeltsin's laboratory (Brookhaven Guide to Russian Scientific Periodical Literature, Vol. 4, No. 11, pp. 335–342, Nov. 1951) stating strongly the case against varitrons. Surely, for some Western as well as Soviet work, the discussion and evaluation must be incomplete and inadequate. If the author's all-or-nothing attitude had been applied consistently, the book would not have been written.

The first two chapters review the

discovery of the μ-meson in cosmic-ray work, and the cosmic-ray experiments bearing on its mass, charge, spin, and magnetic moment. The mass measurements on man-made μ-mesons are left for chapter 4, *Artificially Produced Mesons*.

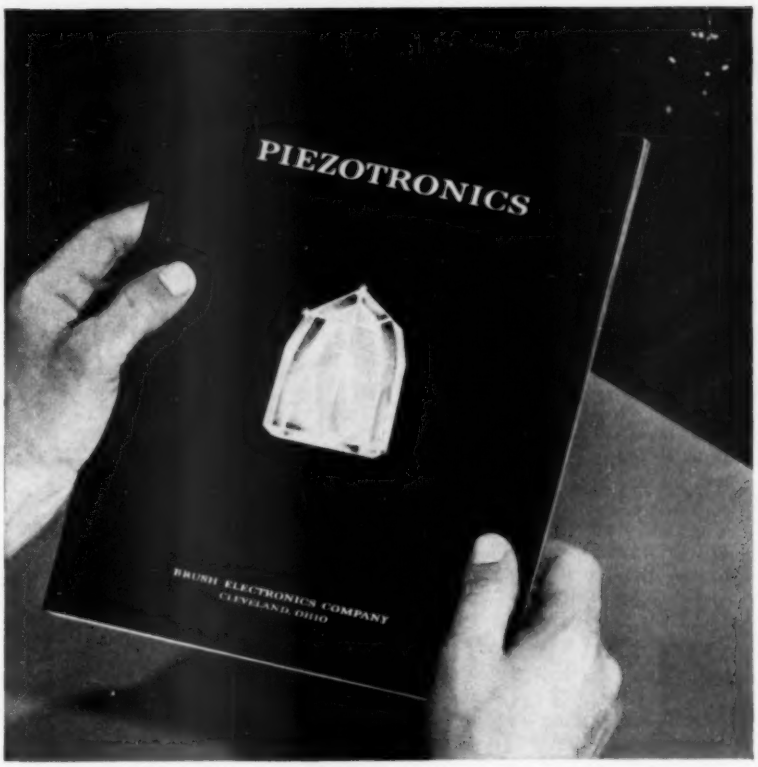
The third chapter, *New Types of Mesons*, recounts in considerable detail the discovery of the charged π-meson by Powell's group, does justice to "varitrons" and "λ-mesons," and concludes with a rather sketchy summary of the properties of the "heavy-mesons"—mass-1,000 charged particles, V-particles, τ-mesons, and K-particles, whose existence is described as "uncertain." The π^0-meson is omitted from this chapter, to be taken up in the next chapter, *Artificially Produced Mesons*. This chapter summarizes the work, done mainly at Berkeley, on the production of charged π-mesons, the masses of $\pi^{\pm}$- and $\mu^{\pm}$-mesons, and the evidence for the existence of the π^0-meson.

Chapter 5 deals with the decay of μ- and π-mesons, the material being presented in full historical sequence. The section on $\mu \rightarrow e$ decay includes the research started by Conversi, Pancini, and Piccioni and extended by Tieho and Valley on the decay electrons from μ^--mesons stopped in various materials, which is more relevant to the next chapter, *Interactions of Mesons with Matter*, than to the decay process itself. One sees here the price paid for arrangement according to experimental technique rather than physical significance. The sixth chapter covers electromagnetic interactions, scattering, nuclear interactions of μ-mesons, and nuclear interactions of π-mesons. Wheeler's argument for an approximate Z_{eff}^4 dependence of the μ^--meson interaction rate is presented somewhat uncritically; it would have been fairer to him to point out, as he did originally, the crudity of the approximations.

Chapter 7 is concerned with the production of mesons in the cosmic radiation. The important experiments are described, with little attempt at synthesis. Chapter 8, *Occurrence of Mesons in Cosmic Radiation*, is a good summary of the facts of life—intensities, energy spectra, and angular distributions—about cosmic-ray mesons.

The book concludes with a "glossary," that is hardly a substitute for the grounding in nuclear physics needed by the reader.

A number of minor errors are to be noted. On p. 46 it is stated "the



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background tends, of course, to become worse the thicker the emulsion." The background depends on the depth of field of the microscope, not the emulsion thickness. In describing the first observed V^0-decay (p. 67), the author states that the event cannot be a π-μ or a μ-e decay "because the particles have opposite electric charge." Cloud-chamber workers will be glad to learn the secret of finding out which way the particle went.

The argument for integral spin of the π^+-meson, given at the bottom of p. 81, is not well put. It only involves the fact that orbital angular momentum is necessarily integral, not a supposed conservation of spin. The conservation law applies only to the total angular momentum. In equation (4), p. 206, the exponent should be 2.9, not 1.9.

The book is a workmanlike summary of past experimental research on μ- and π-mesons, and should, in its emphasis on history and technique, be a very useful reference book for physicists going into meson research. The absence of synthesis makes it ill-suited as a text, especially in view of the availability of the masterly survey of the same ground in chapter 4 of Rossi's *High-Energy Particles* (Prentice-Hall, 1952).

Isotopic Tracers in Biochemistry and Physiology

By JACOB SACKS (McGraw-Hill Book Co., Inc., New York, 1953, vii + 383 pages, $8.50). Reviewed by D. R. H. GOURLEY, Department of Pharmacology, University of Virginia Medical School, Charlottesville, Va.

Several books are available describing numerous experiments in which isotopic tracers have been used as a tool in biochemistry and physiology. Here, at last, is a book which distinguishes between those isotope experiments that serve only to confirm findings well established by the general methods of investigation and those in which the tracer technique is the only one that can pose the question and provide the means for obtaining a definitive answer. The emphasis in this book is on experiments of the latter type, and these have been critically surveyed. The author is well qualified for the task he has set himself, since he has had a long acquaintance with radioisotopes in his own researches.

The point is well established by Dr. Sacks that the use of isotopic tracers

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Q. How does scrap figure in the production of steel?

A. Steel is composed, generally speaking, 50% of pig iron, 25% of "production" scrap (that is, the scrap which is produced as a by-product of steel-making) and 25% of "purchased" scrap.

Q. Is scrap getting scarce?

A. Yes. The supply of *purchased* scrap is not increasing fast enough to meet the needs of increasing steel production.

Q. What if the needed scrap isn't obtained?

A. Open-hearth furnaces will not be able to operate at capacity. That will mean a loss of steel production . . . and fewer products made of steel.

Q. Why not use pig iron instead of scrap?

A. Every ton of scrap conserves approximately 2 tons of iron ore, 1 ton of coal, nearly ½ ton of limestone and many other vital natural resources—to say nothing of the extra transportation facilities that would be otherwise required.

Q. How can *more* scrap be furnished?

A. By everybody pitching in—as we always do in every emergency—and searching out all possible sources of scrap.

Q. What are these sources?

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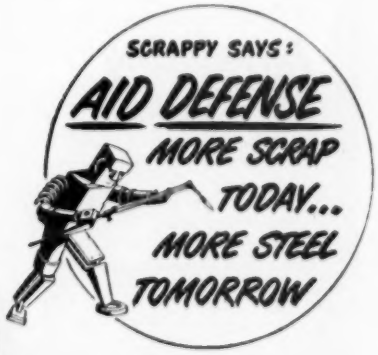
Q. *We* don't *produce* scrap—how can *we* help?

A. Scrap is any kind of iron and steel that's gathering dust—obsolete machines or structures, jigs and fixtures, pulleys and wheels, chains and track, valves and pipe—*anything* with rust on it or dust on it. Non-ferrous scrap is needed, too.

Q. What do we do with it when we find it?

A. Use your normal channels or get in touch with a recognized scrap dealer.



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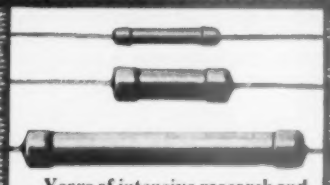

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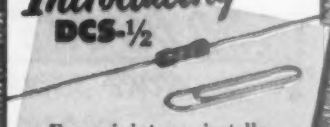

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is a specialized technique, not an end in itself. The details of the experimental technique have been largely omitted, but the broad outlines have been given adequate treatment. Thus, the general principles involved in isotope use, the handling and the measurement of isotopes, have been dealt with in the opening chapters of the book. It is suggested that the reader consult the original references for further details. This approach makes it an excellent book for the biologist to refer to before first attempting to use the tracer technique.

The organization of the remainder of the book is, in some respects, similar to that of many biochemistry texts, dealing with the movement of ions across phase boundaries, carbohydrate metabolism with special reference to the role of phosphorylated intermediates, fat and protein metabolism, nucleic acids and their derivatives, thyroid, blood, trace elements, and photosynthesis. The major accomplishments of the application of the tracer technique in each of these fields have been presented in a fluent style. The material is thus organized by subject rather than by isotope, which greatly adds to its usefulness.

Particularly noteworthy is the section in which Dr. Sacks describes how the nature of the primary condensation product in the tricarboxylic acid cycle was clarified by means of the tracer technique. The chapter on radioiodine and the thyroid gland is also outstanding and should prove useful to clinicians interested in this field.

An excellent summary of the mathematical analysis of tracer experiments on intact animals combines the essential features of the treatments of Zilversmit, *et al.*, and of Siri. The use of these formulations makes it possible to determine whether one isotopically labeled substance meets the necessary conditions for being a precursor of another labeled substance when the stated assumptions are valid. In this connection, the author repeatedly stresses the value of measuring the relative specific activities of compounds under study whenever feasible and of making time-course studies, without which it is impossible to establish precursor-product relations.

In addition to discussing the principles involved in using isotopic tracers as a tool and the major advances that have been made in biochemistry and physiology through the use of this tool, the author has been careful to

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point out many of the limitations inherent in their use. Some of the limitations are presented in general terms in the chapter on the scope of the tracer technique, while mention is made of others in connection with specific problems as they are discussed throughout the book. Dr. Sacks notes that opportunities for misinterpretation of the results of experiments with tracers seem to be greater than in classical experiments. This conviction is repeated several times and can scarcely be overemphasized. However, it may be that as this technique becomes more familiar there will be less tendency to misinterpret results.

On the whole, the book is exceptionally easy to read and understand, and the author has attained his main objectives "to select from the vast and rapidly growing literature those studies which represent major contributions, help to integrate results of other experiments, or serve to illustrate some of the problems and pitfalls that arise in the course of this type of experimentation."

The mechanical details of the book have also been handled with finesse. The illustrations are uniform and clear. There are a large number of up-to-date selected references at the end of each chapter, and a useful table listing the essential properties of the commonly used radioactive tracers appears as an appendix. So much information has now been gained through the use of isotopic tracers in biochemistry and physiology that this book ought to become a standard reference to students in these fields.

BOOKS RECEIVED

Index, Massachusetts Institute of Technology Radiation Laboratory Series, edited by Keith Henney, McGraw-Hill Book Co., Inc., New York, 1953, xxxii + 160, $4.50. The "Index" completes the series of 27 volumes describing the development of microwave theory and radar applications to the end of World War II. Included in the series are: "Electronic Time Measurements," "Electronic Instruments," "Cathode Ray Tube Displays," "Theory of Servomechanisms," and "Computing Mechanisms and Linkages." Introductions to the "Index" describe the history and organization of the Radiation Laboratory.

Introduction to Solid State Physics, by Charles Kittel, John Wiley & Sons, Inc., New York, 1953, xiii + 396 pages, $7.

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NEWS

AEC Awards $300,000 Patent Compensation

Payment of $300,000 as a compensation for partial revocation of a patent granted to seven scientists in 1940, and for infringing use by the Atomic Energy Commission and the Manhattan Engineer District, has been approved by the Commission and its Patent Compensation Board. The patent involved has been assigned to the U. S. Government.

The patent, entitled "Process for the Production of Radioactive Substances," was granted on the basis of work by the seven scientists in Rome prior to 1934. One of the group was Enrico Fermi, who later played a leading role in the development of atomic energy in the United States during World War II.

Bruno Pontecorvo, who disappeared in September, 1950, after flying to Finland from England, and is believed to be in the Soviet Union, also was in the group.

The other scientists who had an interest in the patent are Edoardo Amaldi, Istituto fisico della Universita, Rome; Oscar d'Agostino, Istituto di Sanita Pubblica, Rome; Franco Rasetti, Johns Hopkins University, Baltimore; Emilio Segrè, Berkeley, California, and Guilio Cesare Trabacchi, Istituto di Sanita Pubblica, Rome. Each of them, along with Fermi, held an eighth interest. G. M. Giannini and Co., Inc., of Pasadena, assignee and legal owner of the patent, also held an eighth interest.

The discovery involved in the patent was that radioisotopes of a number of elements can be produced by exposing the elements to neutrons that have been slowed down by passage through a moderating material. This principle has been applied in the atomic energy program.

The patent, granted in 1940, was partially revoked under provisions of Sections 11 (a) (2) and 11 (b) of the Atomic Energy Act of 1946. These sections revoke any patent to the extent that the invention or discovery involved is used in the production of fissionable material or in the utilization of fissionable material or atomic energy for a military weapon, or in research or development activities in these fields. The Act provides "just compensation" for such revocation.

Dean Sees Economic Power Three or Four Years Sooner if Congress Revises Atomic Energy Act

Pleading that Congress "not put too many bonds about our arms and legs simply because there are possibilities of discrimination or unfairness," Gordon Dean, former chairman of AEC, last month spelled out his reasons for supporting a revision in the Atomic Energy Act. In response to specific questions in a letter from Rep. W. Sterling Cole, chairman of the Joint Committee on Atomic Energy, Dean said, "If the law is not changed and if Congress doesn't appropriate funds for the construction of power reactor prototypes in the years immediately ahead, the first 'useful atomic power' will come . . . in Canada or the United Kingdom. If Congress backs the Commission's prototype development program and doesn't change the law, the first full-scale power reactor might be built by the government within ten years. If the Commission's proposals are written into law, the date of the first full-scale economical power reactor might be advanced, in this country at least, by as much as three or four years."

On the question of the possible scale of a U. S. atomic power industry, Dean visualizes four or five prototypes being built with mostly government support in the next five years. In the following five years, he foresees private industry building four or five full-scale plants with its own money.

MTR Data Declassified

Specific information on irradiation facilities, power level, neutron fluxes and coolant temperatures of the Materials Testing Reactor, operated by the Phillips Petroleum Co. in Idaho, has just been declassified. Among the data released are:

Design power	30,000 kw
Coolant	water
Coolant inlet	100° F
Coolant outlet	11° F
Coolant flow rate	20,000 gpm
Fast neutron flux available for irradiations	1×10^{14} n/cm²/sec
Maximum thermal neutron flux available for irradiations	4×10^{14} n/cm²/sec

Reactor Advisory Committees Reorganized

Two advisory committees to the Atomic Energy Commission—the reactor safeguard committee and the industrial committee on reactor location problems—have been combined to form a new group known as the advisory committee on reactor safeguards.

The new committee will have the following functions:

1. Reviewing hazards summary reports prepared by organizations planning to build or operate reactor facilities, including criticality experiments.

2. Advising the AEC regarding the consistency of proposed reactor locations with accepted industrial safety standards, taking into account the proposed exclusion areas for reactors and the proximity of surrounding population and property.

Members are as follows: C. Rogers McCullough, Monsanto Chemical Co., chairman; Manson Benedict, Massachusetts Institute of Technology; Willard P. Conner, Jr., Hercules Powder Co.; R. L. Doan, Phillips Petroleum Co.; Hymer Friedell, Western Reserve University; I. B. Johns, Monsanto Chemical Co.; Mark M. Mills, North American Aviation, Inc.; K. R. Osborn, Allied Chemical and Dye Corp.; D. A. Rogers, Allied Chemical and Dye Corp.; Reuel C. Stratton, Travelers Insurance Co.; Edward Teller, University of California; Abel Wolman,

Johns Hopkins University; Harry Wexler, U. S. Weather Bureau, Department of Commerce; and C. R. Russell, secretary, AEC.

Very little has been said publicly on AEC philosophy regarding reactor safeguards. Therefore, the following statement, made to the Joint Committee on Atomic Energy by Edward Teller, formerly chairman, reactor safeguard committee, is of particular interest:

"Up to the present time we have been extremely fortunate in that accidents in nuclear reactors have not caused any fatalities. With expanding applications of nuclear reactions and nuclear power, it cannot be expected that this unbroken record will be maintained. It must be realized that this good record was achieved to a considerable extent because of safety measures which have necessarily retarded development.

"The main factors which influence reactor safety are, in my opinion, reasonably well understood. There have been in the past years a few minor incidents, all of which have been caused by neglect of clearly formulated safety rules. Such occasional accidents can not be avoided. It is rather remarkable that they have occurred in such a small number of instances. I want to emphasize in particular that the operation of nuclear reactors is not mysterious and that the irregularities are no more unexpected than accidents which happen on account of disregard of traffic regulations.

"In the popular opinion, the main danger of a nuclear pile is due to the possibility that it may explode. It should be pointed out, however, that such an explosion, although possible, is likely to be harmful only in the immediate surroundings and will probably be limited in its destructive effects to the operators. A much greater public hazard is due to the fact that nuclear plants contain radioactive poisons. In a nuclear accident, these poisons may be liberated into the atmosphere or into the water supply. In fact, the radioactive poisons produced in a powerful nuclear reactor will retain a dangerous concentration even after they have been carried downwind to a distance of ten miles. Some danger might possibly persist to distances as great as 100 miles.

"It would seem appropriate that Federal regulations should apply to a hazard which is not confined by state boundaries. The various committees dealing with reactor safety have come to the conclusion that none of the powerful reactors built or suggested up to the present time are absolutely safe. Though the possibility of an accident seems small, a release of the active products in a city or densely populated area would lead to disastrous results.

"It has been therefore the practice of these committees to recommend the observance of exclusion distances, that is, to exclude the public from areas around reactors, the size of the area varying in appropriate manner with the amount of radioactive poison that the reactor might release. Rigid enforcement of such exclusion distances might hamper future development of reactors to an unreasonable extent. In particular, the danger that a reactor might malfunction and release its radioactive poison differs for different kinds of reactors.

"It is my opinion that reactors of sufficiently safe types might be developed in the near future. Apart from the basic construction of the reactor, underground location or particularly thoughtfully constructed safety devices might be considered.

"It is clear that no legislation will be able to stop future accidents and avoid completely occasional loss of life. It is my opinion that the unavoidable danger which will remain after all reasonable controls have been employed must not stand in the way of rapid development of nuclear power. It also would seem that proper legislation at the present time might make provisions for safe construction and safe operation of nuclear reactors.

"It would seem reasonable to extend the AEC procedures on reviewing planned reactors and supervising functioning reactors to nuclear plants under the control of private enterprise. To what extent these functions should be advisory or regulatory is a difficult question. I feel that ultimate responsibility for safe operation will have to be placed on the shoulders of the men and the organizations most closely connected with the construction and the operation of the reactor."

EUROPEAN NUCLEAR RESEARCH got a big push in July when the convention creating the new European Organization for Nuclear Research was signed. Shown at signing are Kowarski (France), Auger (UNESCO), Amaldi (Italy), Bohr (Denmark) and, standing, Dahl (Norway). The $28-million laboratory will be built near Geneva, Switzerland. The twelve signatories and their percentage contributions are: Belgium, 4.88; Denmark, 2.48; France, 23.84; Western Germany, 17.70; Italy, 10.20; Netherlands, 3.68; Norway, 1.79; Sweden, 4.98; Switzerland, 3.71; United Kingdom, 23.84; Yugoslavia, 1.93; and Greece, 0.97. (*Photo Courtesy UNESCO*)

Isotopes Division Reorganizes Staff

The AEC Isotopes Division at Oak Ridge has reorganized its technical staff. The division will now consist of three major branches: allocations, James R. Mason, chief—to review and act upon all applications for isotopic material; radiological safety, G. W. Morgan, chief—to assist radioisotope users in matters of health protection; and technical developments, Edwin A. Wiggin, chief—to prepare and disseminate information on isotope utilization and to outline and encourage training in isotope techniques.

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rector of the division. Charles E. Crompton has been named assistant director and Stephen P. Cobb, Jr., technical assistant to the director.

Government Has No Plans to Press Development of Civilian Nuclear Power

The job of producing electric power from nuclear sources now appears to be strictly up to private industry. At least, the government apparently has no serious plans to build plants for this purpose in the foreseeable future. After a bitter internal row, the Atomic Energy Commission decided last month to put the meager funds—$7-million—appropriated by Congress for reactor construction into a single project which showed little promise for industrial power.

There's little criticism of the Commission for limiting its power reactor construction to a single project. The funds available are barely sufficient for a year's work on such a machine. So the last-minute action of Congress in authorizing AEC to use the money for more than one reactor amounted to little more than euphemizing.

Critics find fault, rather, with the specifications adopted by the Commission for the general characteristics and purpose of the projected PWR (pressurized water reactor).

Details still are not available, but the PWR reportedly will be designed to have a useful electric power capacity of about 50,000 kw. Total cost estimates have ranged as high as $70-million, or $1,400 per kw. This cost ceiling was rejected by AEC, but informed sources have little hope that installation costs will run less than $500 per kw of capacity.

Estimates in this range are well over double the costs of orthodox power producing facilities. According to nongovernment engineers, such a plant would be of little interest to an electric utility company interested in determining the economic feasibility of nuclear power.

Such a plant would be worthwhile, it is conceded, for further experimental work on reactors cooled by high-pressure water. It would be much larger—about three times the power capacity—than the propulsion unit being built by AEC and Westinghouse for the submarine Nautilus. The land-based prototype of this reactor now is undergoing tests at Arco, Idaho.

This leads to another charge leveled at the Commission's decision on the PWR: that it will be of more value as a military project than as a prototype for industrial power production.

This charge was bound to arise after the Commission decided that Rear Admiral Hyman G. Rickover should supervise the PWR project. Rickover, head of the Navy's nuclear power division, had charge of the now-defunct CVR (aircraft carrier reactor) project, as well as the continuing submarine propulsion program. The CVR, which was being designed by Westinghouse, also was to have been a pressurized water unit. Rickover thus was a natural selection to carry on with the PWR job.

But advocates of industrial power development wanted a civilian to head the PWR project. They felt that any Navy man, consciously or otherwise, would tend to guide the PWR program more toward shipboard utility than industrial power lines.

They claim that AEC imposed only two restrictions against such a tendency on Rickover. These forbid the expenditure of additional funds or time on adaptations that would promote the shipboard utility of the PWR.

Critics of AEC's decision on the PWR now are predicting that industry will take the first significant step toward industrial power from reactors. And there are persistent reports that Commonwealth Edison Co., principal industrial power supplier for Chicago, and an associated utility, Public Service Co. of Northern Illinois, are about to seek AEC permission for detailed engineering and architectural designing of a nuclear power plant. According to these reports, the studies will be of a sufficiently advanced nature to permit the two utility firms to make a judgement on the economics of the type of reactor they have in mind—also a pressurized water unit.

Such studies cannot be made by AEC because they fall within the Congressional definition of "construction" as far as appropriations are concerned. AEC is continuing its reactor research program, under which it is able to complete preliminary engineering work. These activities are particularly intense at Argonne National Laboratory, which has been cooperating with Commonwealth Edi-

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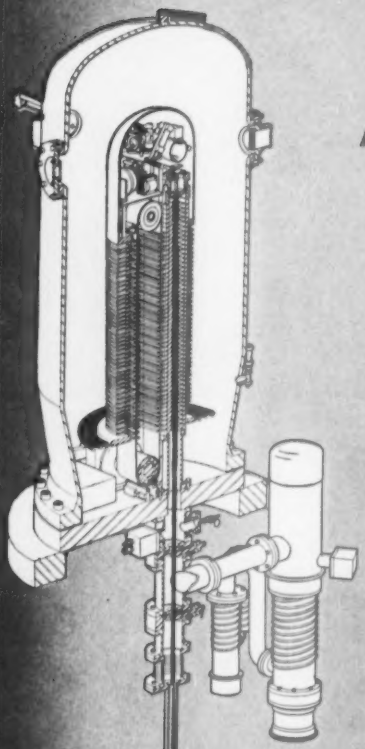

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Plan '54 Gordon Nuclear Chemistry Conference

A third Gordon Research Conference on Nuclear Chemistry sponsored by the American Association for the Advancement of Science, will be held next year. Officers for 1954 will be Gerhart Friedlander (Brookhaven), chairman, and Truman P. Kohman (Carnegie Tech), vice chairman.

For 1954, a large majority of the conference participants favor continued emphasis on nuclear chemistry (taken to mean the study from a chemical viewpoint of the properties and reactions of atomic nuclei) rather than on chemical tracer applications. It is felt that the latter could be more profitably discussed by groups primarily interested in the various fields of application, and that opportunities for this are provided in several of the other Gordon Research Conferences. However, the concensus is that such borderline problems as the role of long-lived radioactivities in geochemistry and the extranuclear effects of nuclear processes should properly be included in the subject matter of future conferences.

About 110 nuclear chemists participated in the second conference, held this past June. The general program was organized by C. D. Coryell (MIT) and I. Perlman (UCRL) with active assistance from the discussion leaders.

Three sessions were devoted to nuclear systematics under the leadership of Katharine Way (NBS), G. T. Seaborg (UCRL), and T. P. Kohman (Carnegie Tech). The individual talks were: L. W. Nordheim (Duke and LASL), "The Shell Model and Regularities in *ft* Values"; K. Way, "Experimental Correlations in β-Decay Energetics and Neutron and Proton Binding Energies"; I. Talmi (Princeton), "Nuclear Forces and the Excited States of Nuclei"; F. Asaro (UCRL), "Complex α Spectra"; J. Huizenga (ANL), "Threshholds for Neutron- and Gamma-Induced Fission"; R. A. Brightsen (Westinghouse), "Nuclear Shell Structure and β-Stability"; and A. E. S. Green (Florida State Univ.), "The Nuclear Mass Surface and Shell Effects."

Somewhat over one session under the leadership of L. E. Glendenin (ANL) was devoted to fission. The

talks were: P. Fong (Chicago), "A Statistical Theory of Fission"; G. B. Cook (Harwell), "Some New Fission Yields"; R. H. Tomlinson (McMaster), "Spontaneous Fission and Neutron Fission in Minerals"; E. P. Steinberg (ANL), "Yields in the Spontaneous Fission of Cm^{242}"; N. Sugarman (Chicago), "Photofission of U^{238}, 16–330 Mev"; M. Lindner (Cal. Res. Dev. Co.), "Activation Functions for Different Products in the Fission of Th^{232} and U^{238} by High Energy Particles"; J. S. Fraser (Chalk River), "Correlation of Neutron Yields with Fission Fragment Energies"; R. B. Leachman (LASL), "Study of Kinetic Energies of Fission Fragments."

High-energy nuclear reactions had two sessions under the leadership of E. Segrè (Calif.) and A. L. Turkevich (Chicago). The talks were: W. Heckrotte, "Models for Nuclear Reactions at High Energy"; J. M. Miller (Columbia), "Simplified Excitation-Evaporation Treatment for Yields with 385 Mev Protons on Co^{59}"; G. Friedlander (BNL), "Nuclear Reactions Induced by 2-Bev Protons in the Brookhaven Cosmotron"; I. Halpern (MIT), "Photonuclear Reactions, Low and High Energy"; A. Zucker (ORNL), "Nuclear Reactions with 25-Mev Nitrogen Nuclei"; and J. M. Hollander (UCRL), "Nuclear Reactions with 120-Mev Carbon Nuclei."

One session each was devoted to physical techniques and chemical techniques under the leadership of G. Friedlander and E. K. Hyde (UCRL), respectively. The talks were: M. L. Perlman (BNL), "Techniques for Measurement of Electron-Capture Disintegration Rates"; A. R. Brosi (ORNL) "Coincidence Spectrometry"; A. W. Schardt (BNL), "Gray Wedge Technique for Scintillation Spectrometry"; R. H. Herber (MIT), "Chemical Separations with Anion Exchange Resins"; J. W. Irvine, Jr. (MIT), "Solvent Extraction Separations"; P. M. Lantz (ORNL), "Techniques for Separation of Tc^{99}, Np^{237}, and Cs^{137} from Highly Radioactive Process Wastes."

The last session was devoted to a survey of spectroscopic and atomic beam methods for nuclear information under the leadership of C. H. Townes (Columbia), who discussed "Summary and Comparison of Spectroscopic Techniques," with talks also by V. Jaccarino (MIT), "Atomic Beams and Nuclear Structure," and W. O. Koski (J. Hopkins), "Preparation of S^{35} Compounds of High Specific Activity."

Public Utilities Group To Survey Atomic Power

The Atomic Energy Commission has approved the request of the National Association of Railroad and Utilities Commissioners for a special committee from that organization to engage in a survey of the atomic power development program.

The association's committee on development and use of atomic power in the electric industry, consisting of six members, will be given access to classified power reactor technology. The committee plans to make a special study of the economic and legislative problems and report to the association's convention next September.

New Isotope Courses Offered at Oak Ridge

The next series of basic courses in the techniques of using radioisotopes in research offered by the Oak Ridge Institute of Nuclear Studies will start Jan. 4, Feb. 8 and Mar. 15, 1954. Information may be obtained from Oak Ridge Institute of Nuclear Studies, P. O. Box 117, Oak Ridge, Tenn.

IN BRIEF

• **Watertown reactor.** Bendix Aviation Corp. has a contract with the Watertown Arsenal for the preparation of specifications and drawings for a nuclear reactor and collateral buildings. The amount of the contract is $50,242.

• **Teletherapy meeting.** There will be a joint meeting of the Oak Ridge Institute of Nuclear Studies and the Isotopes Division with all interested members of the X-ray industry on teletherapy and radiographic problems with isotopes. The purpose of the meeting is to review informally the current thinking of teletherapy design problems, to review the protection requirements for large sources, to discuss the possibilities of the standardization of large source encapsulation, and to review the present status of source manufacture and procurement. All members of the X-ray industry are invited to participate. More detailed information can be obtained from the Medical Division, Oak Ridge Institute of Nuclear Studies, Oak Ridge, Tennessee.

• **Radiological health.** A series of short courses in radiological health—each two weeks in length—are again being presented by the Public Health Service, Environmental Health Center, Cincinnati, O. (address for further details). Tuition free, these course are designed primarily to provide professional personnel in health departments and other groups with a working knowledge of radiation health hazards.

• **Japanese institute.** A national nuclear research institute will be set up in Japan by the educational ministry under a three-year plan.

• **German research.** An association for the promotion of research in nuclear physics was founded last month in Düsseldorf, Germany. Industrial concerns of the Ruhr area, the German electrical industry, the university of Bonn, and the Ministry of Commerce and Transportation of the State of North-Rhine-Westphalia, which back the new association, have decided to set up a cyclotron with a capacity of 30 Mev. The cyclotron will be located in the newly founded Institute for Nuclear Physics at the University of Bonn.

• **New AEC divisions.** Congress has passed an amendment to the McMahon Act that will permit the creation of up to 11 program divisions. Under the original terms of the Act, AEC was to have four program divisions. Actually some seven were created.

• **SAR reactor.** Design work by Knolls Atomic Power Laboratory, with assistance from Argonne National Laboratory, is under way for developing an advanced nuclear power plant for a submarine (SAR) of significantly higher speed than the first two nuclear-powered subs.

NEWSMAKERS

Clyde R. Braun has been named manager of the Allis-Chalmers nuclear power section.

Louis Costrell has been appointed chief of the National Bureau of Standards nucleonic instrumentation section. He is responsible for the development and construction of special instrumentation.

Gordon Dean, former chairman of the AEC, has become associated with the investment banking firm of Lehman Brothers, New York City.

J. H. Hayner, formerly chief chemical engineer, division of engineering, AEC, has been named manager of the newly established atomic energy division of Kaiser Engineers.

A new approach to the Rack-and-Panel Connector problem that provides 30-second replacement and single, accessible point of check for all leads:

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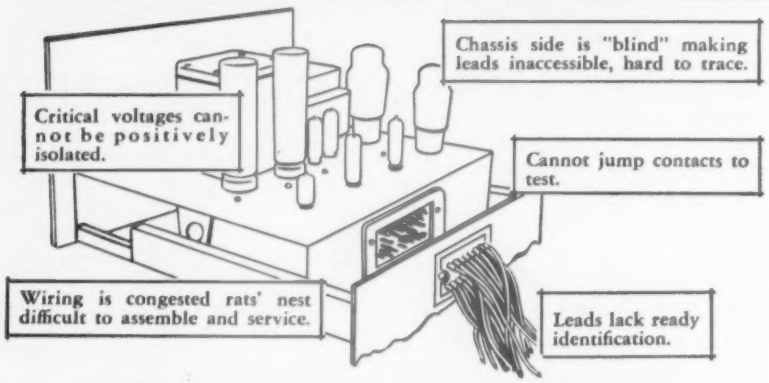
Chassis side is "blind" making leads inaccessible, hard to trace.
Critical voltages cannot be positively isolated.
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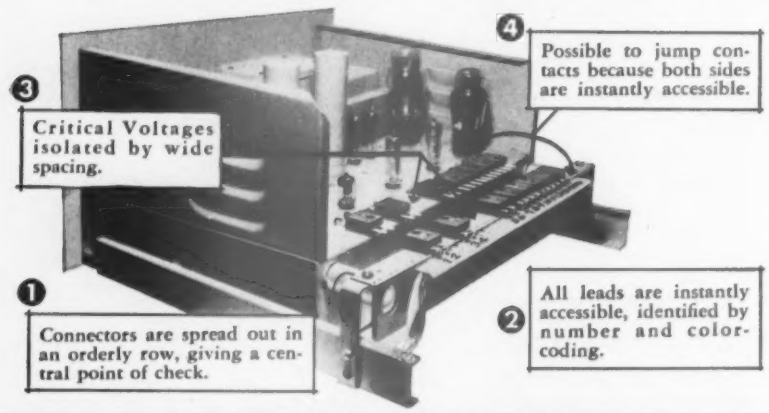
4
Possible to jump contacts because both sides are instantly accessible.
3
Critical Voltages isolated by wide spacing.
1
Connectors are spread out in an orderly row, giving a central point of check.
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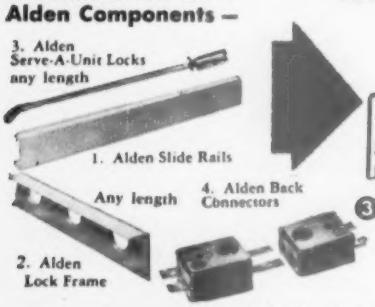
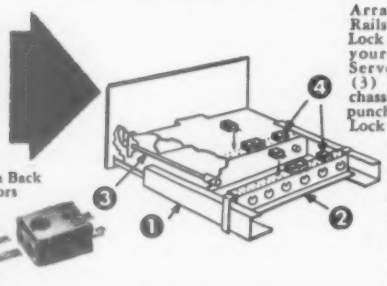


Arrange them like this —



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LETTERS

Permanent Waste Disposal

DEAR SIR:

The writer would like to comment at some length on the article "Economic Evaluation of Permanent Disposal of Radioactive Wastes," by A. C. Herrington, R. Shaver, and C. Sorenson (p. 34), and on the AEC report on which it is based (K-1005). Specifically, I should like to point out the following: (1) that, by itself, this article sheds almost no substantial light on the character of the disposal problem if we are really interested in permanency, and (2) any economic evaluation of the problem at this time is premature.

It would be fortunate indeed if the problem of permanent disposal of radioactive wastes had been reduced to the working level whence only the economic aspects remained to be investigated. This is not the situation, however, and we should have the foresight to recognize that conservation, in its broadest sense, may be at issue.

Is it at all clear, then, that we are prepared to enter the final phase of economic evaluation of the waste problem as the MIT investigators seem to presume? The writer would like to emphasize as strongly as possible that we are not prepared, and any suggestion or implication to the contrary is most dangerous at this time. Statements in support of this conclusion include:

1. The permanent radioactive waste disposal problem is not yet well defined, even as to the amount or nature of the wastes.

2. The future pattern of the atomic energy field is perhaps shaping up, but the possibilities for development are probably as unlimited as imaginable.

3. The significance of our biological environment is becoming more and more a matter of concern to us all, while the tools to probe this environment much further and more precisely are now at hand through application of atomic energy itself.

4. If the beginning of a new industrial era should be at hand, we have a unique opportunity and responsibility to set a course for the handling of wastes from that industry in a manner deemed satisfactory for the future.

5. The irreversibility of the nuclear decay process and any detrimental biological aftermath certainly introduce new factors into the environmental

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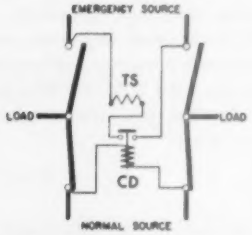

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problem of radioactive waste disposal.

6. There is no reason to confuse the problem of permanent disposal by introducing economic reasoning before the disposal process is evaluated and found to be satisfactory.

The MIT authors may well have made a thorough investigation of the economics of building concrete blocks and transporting them to burial sites, but they have not even attempted to argue that concrete is or is not a permanent kind of material, with or without radioactive additives. It would seem clear that any permanent "packaging" material for long-lived radioactive wastes would want to be rather inert to the destructive actions of corrosion and heat at the very least—so far as is generally known concrete is not indicated on either of these bases.

For the past four years the writer has been associated with an investigation at Brookhaven National Laboratory of the problem of permanent disposal of radioactive wastes. Here the objective is to combine the longer-lived fission products with montmorillonite clay and to fix this combination by heating the clay to about 1,000° C. The capacity of the clay, as measured by cation exchange, is quite adequate for the purpose, (1.1 milliequivalents per gram of clay), and the degree of fixation is promising indeed. But the magnitude of all such factors is dependent on a number of variables such as the nature of the contacting solutions. However, it is expected that the radioactive content of the clay would remain intact for very long periods of time, even in the presence of ionic solutions of sea water strength and after repeated subjection to high temperatures. It is anticipated that the radioactive clay would also be packaged in a container of refractory quality.

On the basis of Brookhaven results* alone, therefore, the writer would take abrupt exception to the statement of the MIT investigators that "disposal in ceramics" is not suitable for high-level wastes. It is in fact the highest level wastes that are of greatest interest for the clay process. Much work has been done at BNL on the firing of the montmorillonite clay, and the resulting fixation of activity within it. The high degree of fixation found is one of the chief reasons why the clay process has been considered promising as a final disposal media.

As for the matter of decontami-

* Published in Quarterly Progress Reports of BNL.

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nation (activity of influent divided by activity of effluent)—again the relative amounts of wastes and of clay as well as the chemical nature of the waste solutions, will predominate. But the Brookhaven objective is to achieve a sufficient decontamination so that the plant effluent could be safely discharged to nature. This objective and the performance of the clay have no relation to a decontamination factor of 30 cited in the article. This value of 30, if taken from the paper by L. Gemmell (ref. *12*), actually has nothing to do with montmorrilonite clay, but is related to the uptake of radioactive ions or organic growths on sand grains.

In conclusion, whether we set out to investigate or demonstrate the merits of one method of disposal or another, it would seem logical not to become entangled with the purely mechanical aspects of the problem (structures, transportation, etc.) until after we attempt to set forth convincing arguments on the very nature of the ultimate disposal problem itself.

—L. P. Hatch
Brookhaven National Laboratory
Upton, New York

Reply: In the absence of the authors (who, as students under my direction, made the economic evaluation reported above), I shall assume the responsibility of making a reply.

A challenge is made to the principal thesis of Hatch, which is summarized by point **6** in his letter.

It is my opinion that research in the field of applied science can be guided intelligently only in light of economic evaluation. The chemical industry has learned that it pays to make an economic evaluation of a new process at the earliest practicable moment. Such evaluations illuminate the need for, and direction of, further work; they provide a basis for assigning (and justifying) the priorities and effort given various phases of the program; they stimulate discussion and often indicate the necessity of approaching the problem from a new viewpoint. The objective of such evaluations is clarification rather than confusion.

The first evaluation will certainly be worthy of substantial modification, and periodic revision will be necessary to demonstrate the benefits gained from progress on technical aspects of the project.

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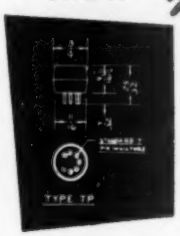

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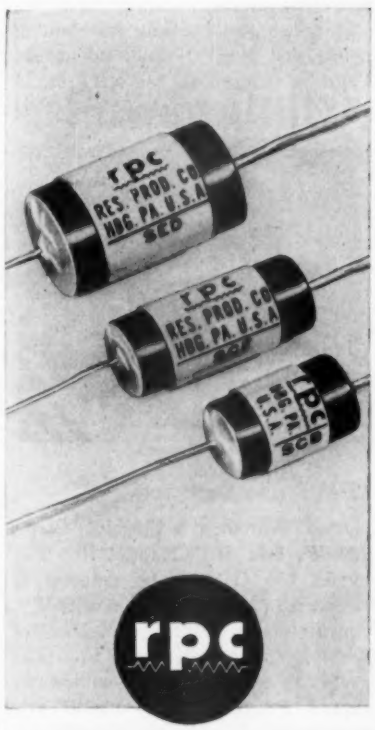

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Beta-Gamma Counter

Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio. The type 6306 bismuth-cathode counter tube is claimed to have an efficiency six times greater than standard tubes for radioiodine and more than twice for radium. The bismuth-screen liner is contained in a 30-mg/cm² aluminum wall. Operating voltage is 900 volts with slope of 5%/100 volts over the 150-volt plateau. (P-2)

Counting Rate Computer

Radioactive Products, Inc., 443 W. Congress, Detroit 26, Mich. The model C-11 counting rate computer is used as an accessory with any scaler to provide a direct reading of average counting rate. It has five automatic preset count ranges; a count-stop-clear lever controls both scaler and computer. At conclusion of counting, a pointer on the computer dial gives the average counting-rate reading directly with a precision of 1%. Maximum counting period is 10 min. (P-3)

Chart of the Elements

Central Scientific Co., 1700 Irving Park Rd., Chicago 13, Ill. This periodic chart of the elements conforms to recommendations of the American Chemical Society Committee on Atomic Weights and the Commission on Atomic Weights of the International Union of Pure and Applied Chemistry. It is lithographed in dark blue and red on heavy plastic-coated paper with metal binding and eyelets for hanging. Three types are available. No. 12051, 29 × 59 in., gives element name, and atomic symbol, number, and weight. No. 12053 includes electronic configuration, naturally occurring isotopes, oxidation states, melting and boiling points, and density. For student use, 12051 is reduced to 8½ × 11 in. in black. (P-4)

G-M Probe Detector

Nuclear Instrument & Chemical Corp., 229 W. Erie St., Chicago, Ill. The model 155 G-M probe detector is designed for tumor location with P^{32}. Sensitive volume of the 3-mm-diameter probe is 9/16 in. long at the tip. The probe is claimed to be sufficiently rugged for continuous surgical use; counting life is said to be virtually unlimited. Model 1615B counting-rate meter and a recorder are available with it as a clinical unit. (P-5)

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discriminator circuit. At maximum gain of 1,500, a 1-mv pulse will trigger multivibrator and negative pulse is delivered to scaler; rise time and decay time are <0.3 μsec. Pulse height discriminator delivers a uniform negative pulse, 0–10 volts, 4.5 μsec long, for every pulse of sufficient amplitude appearing at amplifier output. (P-8)

X-Ray Analysis Calculator

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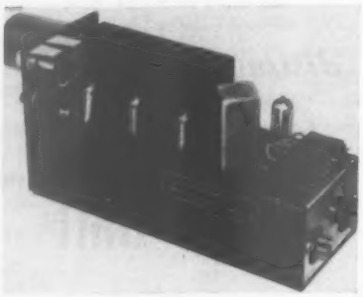

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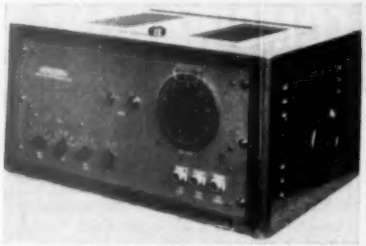
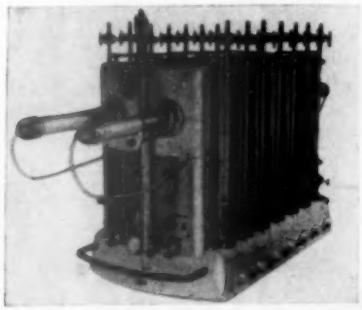


Linear Amplifier

Radiation Instrument Development Laboratory, 2337 W. 67th St., Chicago 36, Ill. The model 418 linear amplifier provides maximum amplifications of 15,000, 10,000, and 3,000 with bandwidths of 0.1, 0.5, and 2.0 Mc, respectively. Rise times are 5.0, 0.8, and 0.2 μsec and decay times are 25, 4.0, and 0.4 μsec, respectively. Coarse gain is variable in 6-db steps from 0 to 30 db; fine-gain attenuation is provided from 0 to 6 db. Maximum usable input signal, positive or negative polarity, varies from 200 μv to 1 mv, depending on rise-time setting. Low-level amplifier output is positive 5-volt pulse across 150 ohms; high-level output is positive pulse, maximum of 100 volts without amplitude distortion. Pulse-height discrimination is variable from 0 to 100 volts. (P-14)



Warburg Apparatus

E. Machlett & Son, 220 E. 23rd St., New York 10, N. Y. The model USL 14-unit Warburg apparatus automatically maintains a temperature constancy of $\pm 0.005°$ C, corresponding to a pressure variation in the reaction

For assistance in developing any type of lead shield,

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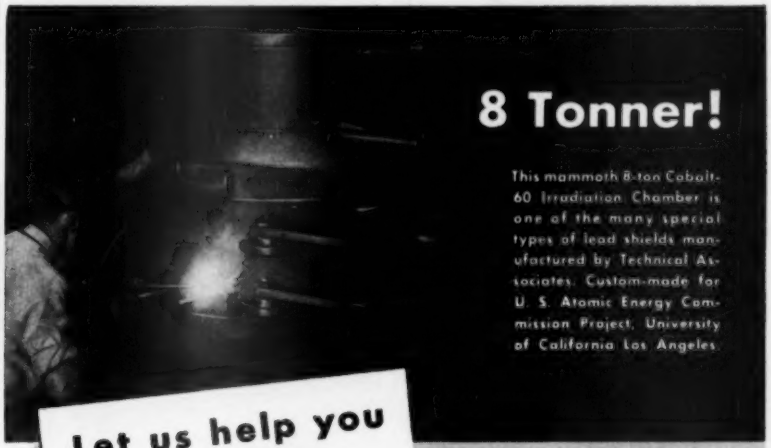

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In addition to the types shown, we are prepared to supply shields to meet specific needs, including side aperture tubular shields for thyroid cancer work, end-opening shields for use in studies of the circulatory system, and many other types. Whatever your lead shield requirement, we can supply it here at Technical Associates.

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We manufacture a large number of useful accessories for lead shields, such as planchets, sample trays, tube mounts, etc. Special equipment can be furnished upon request. Your inquiries are welcome.

Specify Bulletin 128 for full details on lead shields.

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General purpose shield for use with thin-wall counter tubes.

LS-2

Designed for housing all types of mica end-window counter tubes.

LS-4

Useful in determining the radioactivity of liquids and pulverized solids.

LS-5

For thin-wall counter tubes. Recommended when conditions require maximum shielding.

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vessels of 0.01 mm column of water. Shaking amplitude is adjustable from 0 to 8 cm and shaking frequency from 0 to 220 strokes/min. Each manometer can be turned off and on independently. Each bank of seven manometers is controlled by separate rate-control knobs. Two fluorescent lamps run through the bath chamber below the reaction vessels. (P-15)

Digital Voltmeter

Non-Linear Systems, Del Mar, Calif. The Digital Voltmeter indicates voltages in decimal or binary numerical digits at speeds up to 100 readings/sec. Accuracy is 0.1% of input reading or 0.00075 volts, whichever is greater. The decimal point shifts automatically to provide a continuous range of 0.001–999.9 volts. Input impedance is 10 megohms. Calibration is checked with an internal voltage cell. (P-16)

Pulse Amplifier

Utting Associates, Inc., 290 Centre St., Newton 58, Mass. The AP-1A pulse amplifier may be used to drive any scaler sensitive to negative pulses of 5 volts. Switch-selected sensitivities provided are 300 μv for gas proportional counting, 10 mv for scintillation counting, or 300 mv for Geiger counting. Rise time is 0.5 μsec. For most work, a preamplifier is unnecessary. (P-17)

Angstrom Scales

Solus-Schall Ltd., 18, New Cavendish St., London, W.1., England. These unplasticized Perspex Angstrom scales,

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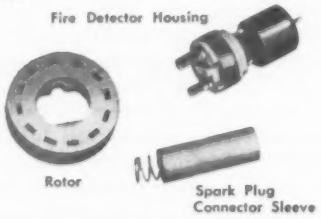

YES, bad conditions can "gang" Mycalex glass-bonded mica, or they can attack it one at a time. Mycalex glass-bonded mica, the only Ceramoplastic, will endure them no matter how they come.

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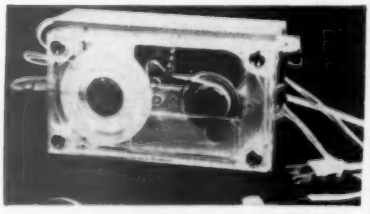
for X-ray powder photography, are graduated in Angstrom units for the standard sizes of cylindrical powder cameras and for common radiations. Where powder films are used for identification of substances, the accuracy of the scales is adequate for searching the ASTM index and for comparing a film, line by line, with tabular data. The scales can also be used for comparing films taken with different X-radiations or different camera sizes. (P-18)

Rotary Switches

Shallcross Mfg. Co., 10 Jackson Ave., Collingdale, Pa. The 60-position (type 10061-S) and 36-position (type 10054-S) single-deck, single-pole rotary switches are designed for range or circuit switching of experimental or heavy-duty test equipment. A detent mechanism provides nonshorting action. Average contact resistance is <0.006 ohms. Current-carrying capacities of 36- and 60-position types are 40 and 30 amperes, respectively; breakdown voltages are 2,500 and 1,500 volts, respectively. (P-19)

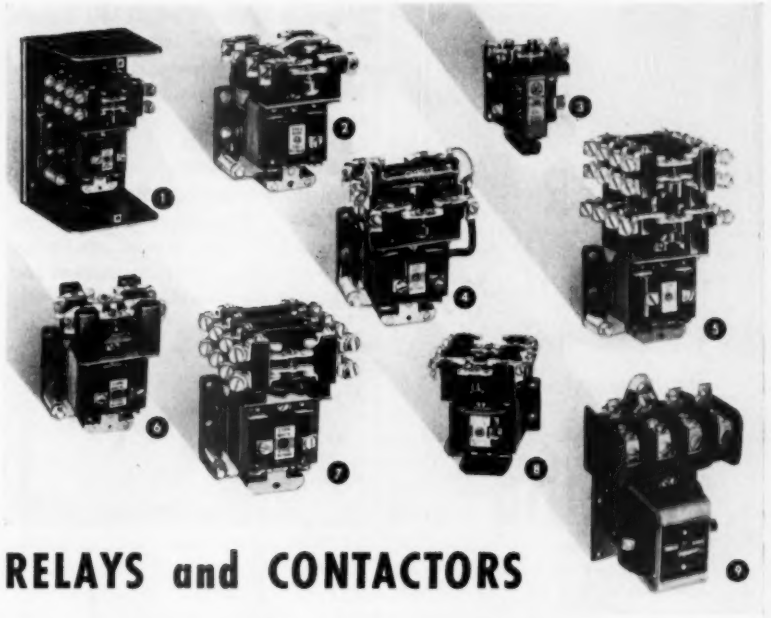
Neon Computer Indicator

Circuit Craft Associates, 5827½ E. Beverly Blvd., Los Angeles 22, Calif. This neon indicator, designed for displaying information in data systems or computers, can be used to replace pilot lights in existing computers. Indicator has an NE-2 type, $\frac{1}{25}$-watt neon lamp and styrene base. Anodized aluminum case, 1.3 in. long, has $\frac{3}{8} \times 32$ thread. Assembly design permits removal of front panel without disconnecting the soldered connection. Interelectrode capacity $<2\mu\mu f$. (P-20)



Action-Recording Monitor

Alden Electronic and Impulse Recording Equipment Co., Westboro, Mass. Utilizing an electrosensitive tape, the



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Type BX universal relays have interchangeable normally open and normally closed contacts. No assembling to change from normally open to normally closed contacts. A few of the relays in the Allen-Bradley line are illustrated above.

Write for Bulletins 700 and 200.

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Fifty ampere contactor in general purpose Type 1 Enclosure.

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2. Type BM Mechanically Held Relay—No Hum
3. Type CL Low Coil Current Relay
4. Type BA 3-Wire Thermostat Relay—Open
5. Type BX 8-Pole Universal Relay—Open
6. Type B 2-Pole A-C Relay—Open
7. Type BX Universal A-C Relay—Open
8. Type BM Mechanically Held Relay—Open
9. Bulletin 202, 2-Pole D-C 25-Ampere Relay

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Magazine Recorder prints and stores a record of separate data traces of two on-off actions plus a timing trace. Normally-on or normally-off switches are activated by any action of 1/6-sec duration or longer. Tape drive is furnished in various speed ranges; one magazine loading can run for as long as 8 days. The magazine, containing tape and recorder mechanism, plugs into drive unit. Drive mechanisms and magazines are interchangeable. (P-21)

Air Centrifuge

Superior Grain Separator Co., 2310 Stevens Ave. South, Minneapolis, Minn. The air centrifuge, available as portable or 7-ft-high models, works on an impelled centrifuge principle to provide continuous dust removal and particle recovery from air. Operation is continuous and nonvarying at temperatures up to 200° higher than standard filters. A perforated rotor allows separation of the gas from the particles. Clean air is propelled upward while solids drop to the bottom and are discharged by a rotary-air-lock outlet. (P-22)

Power Amplifier

Southwestern Industrial Electronics Co., 2831 Post Oak Rd., Houston 19, Texas. The model B direct-coupled power amplifier is said to have essentially flat response from 0 to 20,000

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1832

cycles/sec. Required input is 10 volts or more into a ½-megohm input impedance. Output is 25 volts and 0.25 ampere, maximum. Amplification is voltage, 2.5, power, 30,000. (P-23)

High-Vacuum Valve

Vacuum Research Co., 2050 Orchard Ave., San Leandro, Calif. In the open position, this gate-type, high-vacuum valve has an unobstructed 4-in.-diameter opening. The actuating system, which requires no lubrication, avoids gasket wear by preventing scraping of the gate gasket on the seat. Standard 4-in. pipe flanges are incorporated in the valve, distance between flanges being 8 in. The valve can also be used to handle fluids under moderate pressure. It is available in Permamolded aluminum alloy; gaskets are Hycar rubber. (P-24)

Decade Resistance Box

Brown Electro-Measurement Corp., 4635 S. E. Hawthorne Blvd., Portland 15, Ore. Frequency response of the decade resistance box is up to several hundred kilocycles. Model DB-365 has a range of 0–11,990 ohms in 10-ohm steps; over-all accuracy is ±0.05%. This model is also available with ranges of 119, 1,190, and 119,000 ohms. Model DB-265 is available in values of 11,990 and 119,900 ohms; an interpolating rheostat provides 4-place readings. (P-25)

Potentiometer

Helipot Corp., 916 Meridian Ave., S. Pasadena, Calif. The model Y series potentiometers are available in several mounting styles: threaded bushing for manual operation and flange or two-hole servo mounting, all with either sleeve or ball bearings. External phasing clamp permits phasing after installation. Up to 14 sections are furnished

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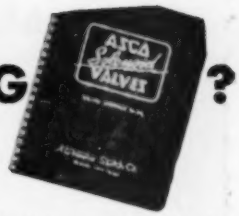

NEW ASCO CATALOG
Describes Scores of Solenoid Valves

New Valve Catalog No. 24 brings you up-to-date on the extensive ASCO line of Solenoid Valves (list prices are included). New valves developed and put on the market recently are described in detail *for the first time*. One of these is:

Bulletins 8262 and 8314
Midget Size 2 & 3-Way Packless Solenoid Valves
Midget Valves are now available with EXPLOSION-PROOF Solenoids for Class 1, Group D hazardous locations. 2-Way (Normally Open or Normally Closed) — Ports, 1/16" through 3/16"; pressures up to 1000 p.s.i. 3-Way — Ports, 3/64" and 3/32"; pressures up to 125 p.s.i. Time Delay Feature — Valves with 3½-6½ seconds delay also available.

These two are just examples of new valve data. If you have *any* need for controlling the flow of liquids or gases in the equipment you are designing or operating, you should find this up-to-date ASCO Valve Catalog useful. Want a copy? Just drop us a note or call up and let us know. We'll be glad to send it to you . . . and extras for your associates if you desire.

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INDEX—Volume 28

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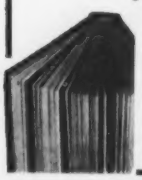
Gives a clear and concise discussion of the signal to noise ratio of nuclear counters and assorted amplifiers, providing good insight into noise and related problems, and the basic material for dealing effectively with such problems. By A. B. Gillespie, Atomic Energy Research Establishment, Harwell, England. 155 pp., 61 illus., $4.50

LOW TEMPERATURE PHYSICS



Describes the physical properties of matter at temperatures below —400 degrees, and shows how these properties obey quantum laws. Also describes advances in the production of low temperatures. By Charles F. Squire, Prof. of Physics, The Rice Institute. 244 pp., 146 illus., $6.50

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INDUSTRY NOTES

▶**Nuclear Instrument & Chemical Corp.,** 229 W. Erie St., Chicago 10, Ill., has begun a film-badge service for interpretation of accumulated X- and gamma radiation over a range of 50 mr to 500 r with energies from 50 kev to 20 Mev. Badges are furnished on a weekly basis. Badge number, date worn, and wearer's name appear on outside of film packet and on emulsion.

▶**Technical Operations, Inc.,** 6 Schouler Court, Arlington 74, Mass., will offer this fall the first in a series of 2-week training programs in Co^{60} radiography in industry. The program is divided equally between lecture and actual practice. Applicants should have previous technical training or experience in foundry practice, steel fabrication, mechanical engineering, radiography, or related fields. Enrollment is limited.

▶**Vitro Corp. of America, Vitro Mfg. Co., and Vitro Chemical Co.,** 233 Broadway, New York 7, N. Y., have elected J. Carlton Ward, Jr., as president of the corporations. Charles S. Payson was elected chairman of the boards of directors. Mr. Ward founded and headed NEPA.

▶**Westinghouse Electric Corp.,** 401 Liberty Ave., Pittsburgh 30, Pa. has received orders totaling $4,053,000 for more than 1,000 electric motors to be used in AEC projects. The motors range from 350 to 950 horsepower.

▶**Tracerlab, Inc.,** 130 High St., Boston, Mass., offers an intensive, 2-day training course to provide the basic knowledge needed for use of Co^{60} in industrial radiography.

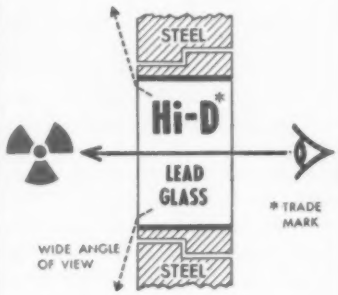
LITERATURE AVAILABLE

Nuclear instrumentation. Catalog M, illustrated, gives specifications and price list of radioactivity instruments and accessories. *Nuclear Instrument & Chemical Corp., 223 W. Erie St., Chicago 10, Ill.* (L-1)

Corrosion-resistant chemical equipment. Bulletin CHE-R4 describes characteristics of porcelin, stoneware,

Hi-D*

LEAD GLASS WINDOWS IN STEEL WALLS



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plastic (phenolic resin with carbon filler), and graphite (resin-impregnated graphite) equipment. *General Ceramics and Steatite Corp., Chemical Equipment Div., Keasbey, N. J.* (L-2)

Radiation protection instruments. Bulletin C-3 describes quartz-fiber-electroscope and ionization-chamber instruments suitable for civil defense. *Landsverk Electrometer Co., 550 W. Garfield Ave., Glendale 4, Calif.* (L-3)

Organic chemicals. Price lists are available for amino acid L- and D-isomers and other organic chemicals. *Schwarz Laboratories, Inc., 230 Washington St., Mount Vernon, N. Y.* (L-4)

Ceramics. Bulletin 533 tells advantages of AlSiMag technical ceramics in nontechnical terms. *American Lava Corp., Chattanooga 5, Tenn.* (L-5)

Stainless steel filters. Brochure describes filter crucibles, Buchner funnels, and gas-dispersion tubes. *Micro Metallic Corp., Glen Cove, N. Y.* (L-6)

Film badge service. Issue 3 of "The Nucleus" describes film service and radiation equipment. *Nuclear Instrument & Chemical Corp., 223 W. Erie St., Chicago 10, Ill.* (L-7)

Radiation measuring apparatus. Catalog gives data on detection and measuring instruments. *Radiation Instrument Development Laboratory, 2337 W. 67th St., Chicago 36, Ill.* (L-8)

Electrical resolver systems. Specifications are given for systems including summing network box, high-gain computing amplifier, and resolver. *Ford Instrument Co., 31-10 Thomson Ave., Long Island City 1, N. Y.* (L-9)

A-C line regulators. Catalog 353 gives information on electronic regulators and electronic frequency changers. *General Sales Dept., Sorensen & Co., Inc., 375 Fairfield Ave., Stamford, Conn.* (L-10)

Continuously adjustable transformer. Brochure describes line of Variac transformers with Duratrak construction to reduce oxidation of transformer winding. *General Radio Co., Cambridge 39, Mass.* (L-11)

Radioisotopes. Leaflet FS-231 describes radioactive reagents; bibliography included. *Fisher Scientific Co., 711 Forbes St., Pittsburgh 19, Pa.* (L-12)

Beryllium products. Pure metal, oxide, and alloys described in "Product Directory." *Beryllium Corp., Reading, Pa.* (L-13)

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These models available with positive side grounded.

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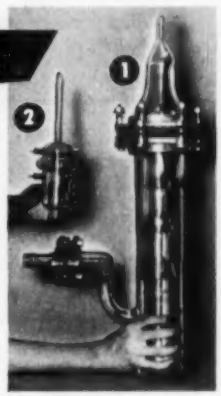

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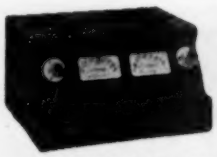

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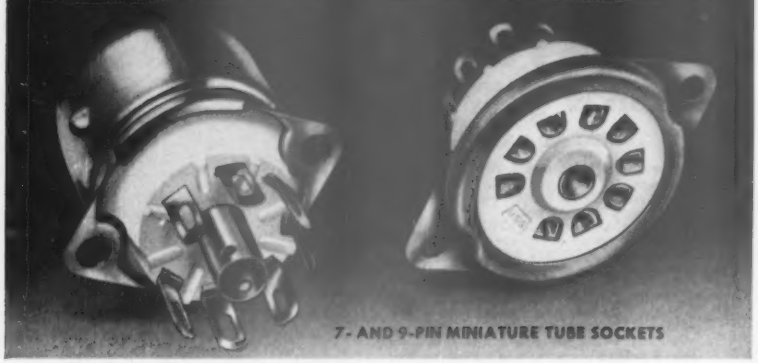

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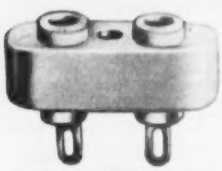

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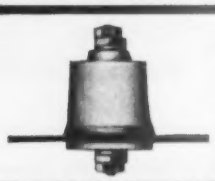

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